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## **Forecasting of mobile handset feature diffusion: supply-related aspects**

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<p>Mobile handsets gradually evolve into computer-like devices. Hence, contemporary smartphones are capable of running complicated mobile applications, many of which are enabled by different mobile handset components, or features. Therefore, mobile application and service providers are increasingly interested to know the corresponding market potential for their applications and services, that is, diffusion of related handset components. Feature diffusion depends on a primarily supply-driven process of the component penetration in sales, which is referred to as feature dissemination.</p> <p>This thesis analyses the phenomenon of mobile handset feature dissemination and investigates the ways in which forecasting of feature dissemination and diffusion can be improved. First, the evolution of mobile handset population in Finland was studied based on operators' data in order to obtain a better understanding of the focus market. Then, dissemination of mobile handset features was analysed quantitatively based on handset sales information. Finally, the processes underlying the phenomenon of feature dissemination were studied qualitatively using a method of expert interviews.</p> <p>Quantitative analysis revealed that dissemination of some features is interdependent and relationships between the features have a hierarchical pattern. Expert interviews showed that the feature dissemination is a complicated phenomenon, affected by different factors and decisions of industry stakeholders. Furthermore, based on the interview outcomes, it was concluded that the forecasting of feature dissemination can be improved by considering the costs of hardware components, effects of chipset integration and demand for feature-enabled mobile applications.</p>		
<b>Keywords:</b> Diffusion, product feature, mobile handset, dissemination		

## **Preface**

This Master's Thesis has been written as a partial fulfilment for the degree of Master of Science in Technology in Aalto University, School of Electrical Engineering. The work was carried out in the Department of Communications and Networking, in the Networking Economics research group.

I wish to express my gratitude to the people who have supported me throughout this thesis work. First of all, I would like to thank Professor Heikki Hämmäinen for the opportunity to write this thesis in his team under his guidance. I am grateful to Antti Riikonen for his extensive assistance and support throughout the whole research process. Furthermore, I would like to thank interview participants for their valuable insights.

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Alexandr Vesselkov

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# **1 Introduction**

## **1.1 Motivation**

The mobile handset has come a long way since 1973, when the prototype of the first handheld device named DynaTAC was demonstrated by Motorola (Motorola, 2014). From that moment, the mobile handset began its gradual evolution from being an attribute of luxury to becoming an indispensable means of communication; from the basic feature phone with voice-only capability to the advanced smartphone capable of running complicated applications.

The evolution of the mobile handset into a computer-like device drove the emergence of numerous mobile applications and services oriented to smartphone users. Many applications are enabled by a particular hardware or software component or feature of mobile handset (Riikonen, Smura, & Juntunen, 2011). For example, location-based services often require the GPS (Global Positioning System) feature for the operation, whereas mobile video conferencing needs, at minimum, 3G (third generation) connectivity for satisfactory user experience. Therefore, mobile application developers and service providers are increasingly interested in the information about installed base of particular mobile handset features and forecasting features' future penetration, or diffusion.

The question of innovation diffusion is not a new one; the foundations of the innovation diffusion theory are well-established. Much attention has been paid to the reasons driving an innovation, to the attributes of successful innovation, and the factors affecting the rate of innovation adoption (Rogers, 2003). Mathematical models of innovation diffusion (see Mahajan & Peterson, 1985 for overview) provide reasonably accurate estimates of future adoption of an innovative product. However, little attention has been paid to the question of the diffusion of new product components. Indeed, when the product matures and the market saturates, product sales start to be dominated by replacement purchases. Often replacement for the old product unit is an evolved version of the product, containing new components (as in the cases of the mobile handset, laptop, or car). Therefore, while product category-level diffusion models do not allow taking into account the adoption of new product components, this process is of great interest.

One of the few studies addressing the question of modelling the diffusion of new product components is the work by Kivi, Smura, & Töyli (2012). In the developed forecasting framework, the authors acknowledged the impact of a supply-driven process of feature dissemination, or penetration in sales, on the feature diffusion. However, they did not examine the factors underlying the process of feature dissemination and assumed that a simplistic method of forecasting by analogy could provide precise dissemination estimates. This thesis attempts to improve the accuracy of the feature diffusion forecasting framework by studying the process of feature dissemination in more detail, and, therefore, it can be considered as a continuation of the work by Kivi et al. (2012). The thesis, in line with Kivi et al. (2012), focuses on the example of mobile handset features diffusion in Finland.



## 1.2 Research questions and objectives

The thesis research focuses on improving the accuracy of mobile handset feature diffusion forecasts by considering the processes underlying the dissemination of product features. Moreover, the thesis studies the relations (or interdependencies) between the dissemination of different features. Thus, the main research question this thesis aims to answer is:

Q: How to improve the forecasting of mobile handset feature diffusion by considering the processes underlying the dissemination of mobile handset features?

- a. What is the historical evolution of mobile handset market in Finland?
- b. What are the interdependencies between dissemination of different mobile handset features in Finland?
- c. What are the main factors and industry stakeholders affecting the dissemination of mobile handset features?
- d. What are the main directions of the improvement of feature dissemination forecasts?

The research objectives are defined in order to support answering the stated research questions:

1. Analyse the historical evolution of mobile handset market in Finland.
2. Analyse the historical patterns of mobile handset feature dissemination in Finland and test interdependencies between them.
3. Identify the main factors affecting the dissemination of mobile handset features.
4. Identify the main stakeholders of mobile handset industry and analyse the ways in which they affect the dissemination of mobile handset features.
5. Suggest the ways of improving the mobile handset feature dissemination forecasting.

The first objective is necessary to fulfil in order to obtain holistic understanding of the focus market. Studying the historical patterns of mobile handset feature dissemination (the second objective) is critical for uncovering the connections between different features and concluding about their importance for answering the research question. The third and fourth objectives are needed for revealing the essence of the phenomenon of mobile handset feature dissemination. Finally, the last objective is required for collecting all research findings and improving the forecasting of mobile handset feature dissemination and diffusion.

## 1.3 Methodology

A **literature study** is conducted to gain the understanding about the phenomena of technological innovation and diffusion of innovation. Particular attention is paid to the drivers of technological innovations, as well as to the mathematical models of innovation diffusion.

**Quantitative study** based on the active mobile handset population data from mobile operators is utilised for analysing the evolution of mobile handset base in Finland and historical diffusion of mobile handset features. Furthermore, the interdependencies

between mobile handset features dissemination are studied quantitatively based on mobile handset sales data.

**Qualitative study** based on the expert interviews is conducted for discovering the factors underlying the mobile handset feature dissemination. Seven semi-structured interviews allow analysing the question from different points of view and collecting unique information which is difficult to obtain from the literature or other freely available sources.

#### **1.4 Thesis structure**

The thesis is further structured as follows: Chapter 2 covers the research background information by presenting a short selective review of the relevant theories of technological change and the essentials of innovation diffusion theory. Research data and methods are presented in Chapter 3. Chapter 4 shows the results of the descriptive analysis of Finnish mobile handset population. Historical patterns of mobile handset feature dissemination are analysed in Chapter 5. Chapter 6 presents the results of qualitative study of the feature dissemination process based on the expert interviews. Finally, Chapter 7 provides conclusions of the thesis, discusses advantages and limitation of the study, and suggests questions for future research.

## **2 Background theory**

Innovation and invention are two terms which are often used interchangeably in everyday speech; however, they have clearly different meanings. Invention is a formulation of something new – an idea, a device, an artefact. Innovation, in turn, means the practical application and adoption of an invention by the members of a social system. Therefore, *adoption by a social system or diffusion* is an important element, which separates these two phenomena. Indeed, not every invention however ingenious and rational can eventually become an innovation (Denning, 2004). Thus, one of the important parts of innovation studies is diffusion of innovations, which addresses the ways in which new ideas spread among populations, and examines the reasons of innovation adoption. Rogers' book named "Diffusion of innovations" (Rogers, 2003), first published in 1962, is a prominent work which integrates the main ideas of this theory.

Understanding the theoretical concepts of innovation diffusion is important; however, practitioners are often more interested in innovation diffusion forecasting, or estimating the number of adopters as a function of time. For this purpose, diffusion researchers utilise numerous mathematical models, most of which, however, focus on the diffusion of innovative product as a product category. These models have little use for the estimation of new product features' diffusion, although this is essential for describing the evolution of high technology products such as the mobile handset, laptop, or car.

The rest of the background chapter is structured as follows. The selected theories of technological change are reviewed in Section 2.1. The basic concepts of Rogers' theory of innovation diffusion are presented in Section 2.2. Section 2.3 discusses the modelling of innovation diffusion. Finally, the diffusion of new product features is examined in Section 2.4.

### **2.1 Theories of technological change**

#### **2.1.1 Driving forces of innovation: technology push vs market pull**

One of the typical debates of innovation researchers is whether successful innovations are normally driven by technological changes (technology push) or market demands (market pull). Technology push approach suggests that the innovation is caused by the change in technology which is in turn induced by science and research and development (R&D) activities. In contrast, market pull explains the emergence of successful innovations by the fulfilment of market demands. Chidamber and Kon (1994) conducted a survey of empirical studies and found that some of the works supported the idea of technology push as a key innovation driver, whereas some other empirical research defended the idea of market pull. The authors argue that this disagreement between the reviewed studies demonstrated that "both market need and technical capabilities are necessary conditions for innovation success", but neither alone is a sufficient condition. Therefore, they claim that the conflicting results of technology push – market pull studies can mean that the theories are complementary, rather than contradictory as has been thought before.

Similarly to Chidamber and Kon (1994), Walsh, Kirchhoff, and Newbert (2002) supported the idea of the complementarity of technology push and market pull concepts. They argue that these two approaches represent the extremes of a continuous scale describing the drivers of innovation. Thus, the authors claim that the reason behind the innovation is typically a mixture of technology and market factors, with individual compositions for different cases. The results of their empirical studies show that established firms tend to adopt market pull strategy, while a larger share of new firms typically implement technology-push strategy.

Another viewpoint on the question of technology push – market pull was presented by Gerpott (2005). He argues that technology push and market pull approaches can coexist, but the former accounts for radical innovations, whereas the latter explains incremental, stepwise innovations. Differences in the attributes of the technology push and market pull approaches discussed in Gerpott (2005) are summarized by Brem and Voigt (2009) and presented in Table 2.1.

**Table 2.1. Technology push vs. market pull (Brem & Voigt, 2009)**

Description/attribute	Technology push	Market pull
<b>Technological uncertainty</b>	High	Low
<b>R&amp;D expenses</b>	High	Low
<b>R&amp;D duration</b>	Long	Short
<b>Sales market-related uncertainty</b>	High	Low
<b>Time-to-market</b>	Uncertain / Unknown	Certain / Known
<b>R&amp;D customer integration</b>	Difficult	Easy
<b>Kinds of market research</b>	Qualitative – discovering	Quantitative – verifying
<b>Need for change of customer behaviour</b>	Extensive	Minimal

While the market and technology factors are undoubtedly among the main determinants of innovations' emergence, it is obvious that they cannot explain the occurrence of every single innovation. One example is so-called “green” or eco-innovation, which is often driven not by the market or technology, but by the authorities' regulations (see for example, Porter & Van der Linde, 1995). Similar cases can be found in other fields, for instance, in telecommunications. Famous example is the “Carterfone decision” referring to the order of the Federal Communications Commission (FCC) of the US issued in 1968 which allowed attaching any suitable devices to the telephone network without asking permission from the operator. This order enabled the development of innovations in the sphere of subscribers' equipment and, as claimed by Wu (2007), drove the popularization of fax machines, answering machines, and modems.

### 2.1.2 Ecosystem view on innovation

The term “business ecosystem” was first defined by Moore (1996) as an economic community, consisting of producers, customers, suppliers, competitors, and other stakeholders, whose capabilities and roles coevolve over time and “tend to align with ... the directions set by one or more central companies”. The concept of a business ecosystem is close to the idea of a value network, which can be defined as “a set of interlinked (business) actors and technical (or more generically functional) resources that work together to create economic value through services and products” (Casey, Smura, & Sorri, 2010). Although the definitions are quite similar, there are also differences between the concepts, as shown in Table 2.2 (Peltoniemi, 2005).

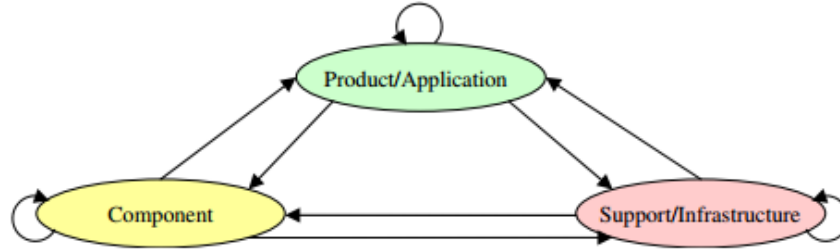
**Table 2.2. Comparison of key features of value network and business ecosystem (Peltoniemi, 2005)**

	Value Network	Business Ecosystem
<b>Geography</b>	Anything from local to global	Rejects the role of geography
<b>Competition and cooperation</b>	Cooperation	Both simultaneously
<b>Industry</b>	Different industries complement each other	Finds the term “industry” obsolete
<b>Knowledge</b>	Limited to operative information	Interconnectedness as the enabler and shared fate as the motivator of cooperation
<b>Control</b>	One powerful actor	Decentralised decision making

Tight interconnections between the stakeholders of a value network or business ecosystem have an effect on the ways in which innovations emerge, launch, and diffuse. Adner and Kapoor (2010) studied the process of value creation in innovation ecosystems and found that the innovation can rarely be implemented by one distinct firm; more often it requires acquisition of new capabilities by at least several other members of the ecosystem. The authors illustrated this idea by an example of the world’s largest passenger aircraft Airbus A380. For A380’s building and operation, substantial investments were required not only from Airbus, but also from suppliers, which had to produce new aircraft components; from airports, which had to invest in infrastructure; from regulators, which had to specify new safety procedures; and from training simulator manufacturers, which had to design new machines. Moreover, Adner and Kapoor (2010) found that while producers typically acknowledge and consider the role of suppliers in the emergence of an innovation, they often underestimate the effect of complements on the innovation diffusion.

The ecosystem approach of technology evolution was also considered by Adomavicius, Bockstedt, Gupta, and Kauffman (2007). The study argues that technology evolution is influenced by the development of other interdependent technologies. The authors identified

three specific roles which technologies can play in an ecosystem: the component role, the product and application role, and the support and infrastructure role. They claim that technologies interact through these roles and affect each other's evolution, defining nine possible paths of influence presented in Figure 2.1. Examples of the paths of influence can be found in the evolution of mobile handset and mobile telephony, as shown in Table 2.3.



**Figure 2.1. Temporal interactions among technology roles (Adomavicius et al., 2007)**

**Table 2.3. Paths of influence: examples from mobile handset and mobile telephony (based on Adomavicius et al., 2007)**

	Component-oriented path of influence $C^*$	Product-oriented paths of influence $P^*$	Infrastructure-oriented paths of influence $I^*$
C	<p><i>Component integration and evolution <math>C \rightarrow C^*</math></i></p> <p>Integration of WLAN and Bluetooth chips on one chipset</p>	<p><i>Design and compilation <math>C \rightarrow P^*</math></i></p> <p>Development of smaller chips enables the production of smaller mobile handsets</p>	<p><i>Standards and infrastructure development <math>C \rightarrow I^*</math></i></p> <p>Development of a new mobile operating system often drives the emergence of related application store</p>
P	<p><i>Product-driven component development <math>P \rightarrow C^*</math></i></p> <p>High energy consumption by smartphones drives the development of low energy consuming combo-chips</p>	<p><i>Product integration and evolution <math>P \rightarrow P^*</math></i></p> <p>Navigators and cameras – two different products are now integrated in smartphones</p>	<p><i>Diffusion and adoption <math>P \rightarrow I^*</math></i></p> <p>Higher number of NFC-enabled handsets drives the growth of the number of NFC payment systems</p>
I	<p><i>Infrastructure-driven component development <math>I \rightarrow C^*</math></i></p> <p>Wider usage of NFC payments drives the integration of in the newest combo-chips</p>	<p><i>Infrastructure-leveraging product development <math>I \rightarrow P^*</math></i></p> <p>Wider coverage of LTE drives the emergence of higher number of LTE handset models</p>	<p><i>Support integration and evolution <math>I \rightarrow I^*</math></i></p> <p>Evolution of radio access technologies from 2G to 3G and 4G</p>

It should be noted that an object can play different technology roles at the same time, depending on the product or perspective. For example, smartphone operating system can

be thought of as a component or infrastructure, if the focus product is the smartphone or mobile application respectively.

The ecosystem view on innovations presented in Adomavicius et al. (2007) provides a starting point for investigating the drivers and the dynamic nature of technological change. However, it has some limitations. Particularly, it does not take into account external forces which undoubtedly have an impact on the technology evolution.

### 2.1.3 Launching new product features

Few innovation studies have addressed the question of the diffusion of new product features, and almost no research has considered the problems of their emergence and launch. One of the few papers investigating the theory and practice of launching new product components is the work by Thölke, Hultinka, and Robbenb (2001). In the study, the authors acknowledged a role of innovative features for product differentiation in mature markets and analysed several feature launch decisions described in Table 2.4.

**Table 2.4. Feature launch decisions (based on Thölke et al., 2001)**

Feature launch decision		Example*
Position in the feature life cycle	When to introduce a new feature?	The GPS feature was first introduced in a mobile handset in 1999, when it was immature. Nokia introduced first multi-touch handset in 2010, several years later than competitors did.
Core technology of the feature	Which core technology to use for the development of new features – fundamentally new or applied and proven?	Improvement in smartphone battery: manufacturers can either invest heavily in design of the batteries based on new technologies or continue gradual evolution of conventional lithium-ion batteries.
Focus of the product line strategy	What to focus the product line strategy on: feature or integrated product?	The advertisement of LG G Flex is focused on the curved flexible display (feature), whereas Apple does not emphasize separate features, but advertises the overall enhanced experience of the iPhone 5S usage (product).
Feature diffusion in the product line	How to diffuse the feature in the product line: top-down diffusion, selective diffusion, or broad diffusion approach?	Typically mobile handset producers use top-down approach: the feature is first launched in high-tier handsets, then in mid-tier and low-tier devices. However, Nokia launched enhanced music capability feature using broad approach,

		addressing different market segments roughly at the same time <sup>1</sup> .
Make or buy	Is it better to develop own manufacturing for the feature or buy it from a supplier?	Samsung uses mixed strategy, producing some features independently and buying some from suppliers.

\* The presented examples substitute the ones presented in Thölke et al. (2001)

Based on the feature launch decisions, Thölke et al. (2001) identified four feature launch strategies: dictatorship, pioneering, establishing, and following. However, in mobile handset business, two of them can be typically observed: dictatorship and pioneering strategy. In dictatorship strategy, producers launch a feature when it is new to the industry or product category, the feature is typically based on fundamentally new technology, and a product strategy is focused on the innovative feature. The difference of the pioneering strategy is that it implies less investment in R&D and, therefore, innovative features are often based on applied and proven technologies. In both strategies manufacturers can rarely launch the innovative feature without collaboration with the component producers.

## 2.2 Fundamentals of innovation diffusion theory

### 2.2.1 Main elements of innovation diffusion

Rogers (2003) defines diffusion as “the process by which an *innovation* is *communicated* through certain *channels* over *time* among the members of a *social system*” (p. 5). The definition highlights four main elements of innovation diffusion: innovation, communication channels, time, and social system.

**Innovation** is the object being diffused. From the technological point of view, innovation can be defined as a “technologically new products and processes and significant technological improvements in product and processes” (OECD/Eurostat, 1997, p. 32). The diffusion of innovations occurs through certain **communication channels**. According to Rogers (2003), diffusion is communicated by means of mass media channels and interpersonal channels. Mass media channels are considered to be an efficient and fast means of informing potential adopters about the innovation and building awareness knowledge, whereas interpersonal channels are more critical for making an adoption decision.

**Time** is the third important element of the diffusion process. The inclusion of the time in diffusion research is necessary because the process of innovation diffusion does not happen rapidly; instead, it typically occurs over a long period of time. Rogers (2003) divided this process, known as the “innovation-decision process”, into five consequent steps: knowledge, persuasion, decision, implementation, and confirmation. The process begins when an individual gains knowledge of the innovation (first stage); after that he forms the opinion about the usefulness of the innovation (second stage); later he makes a decision to

<sup>1</sup> For example, the prices of the models of the late 2008 – 2009 in Finland in the beginning of first sales (according to GfK): Nokia 5800 XpressMusic ~ 400 euro, Nokia 5730 XpressMusic ~ 320 euro, Nokia 5130 XpressMusic ~ 150 euro



adopt or reject the innovation (third stage); thereafter, in case of the adopting decision, the individual goes to the stage of idea implementation and usage (fourth stage), and finally he makes a conclusion about the correctness of his adoption decision (fifth stage). Thus, adoption and rejection of innovation are two possible outcomes of the innovation-decision process.

**Social system** is the last element of innovation diffusion, defined by Rogers (2003, p. 23) as “a set of interrelated units that are engaged in joint problem solving to accomplish a common goal”. Depending on the structure of a social system, innovation decisions can be optional, when the members of a social system independently make decisions on the adoption or rejection of innovation; collective, when the innovation decision is made by the majority of a social system, and authority, when few individual decision makers choose whether to adopt or reject the innovation.

### **2.2.2 Factors affecting the rate of innovation adoption**

An important aspect of the innovation adoption is the rate of adoption, defined as the “relative speed with which innovation is adopted by members of a social system” (Rogers, 2003, p. 23). Factors influencing the rate of adoption are connected with the *attributes of innovation* perceived by the potential adopters. As described in the previous section, before applying the innovation, the adopter goes through these five steps of the innovation-decision process. At the stage of persuasion, the individual evaluates the usefulness of the innovation. Rogers (2003) claimed that the following five attributes of innovations are the most important for potential adopters:

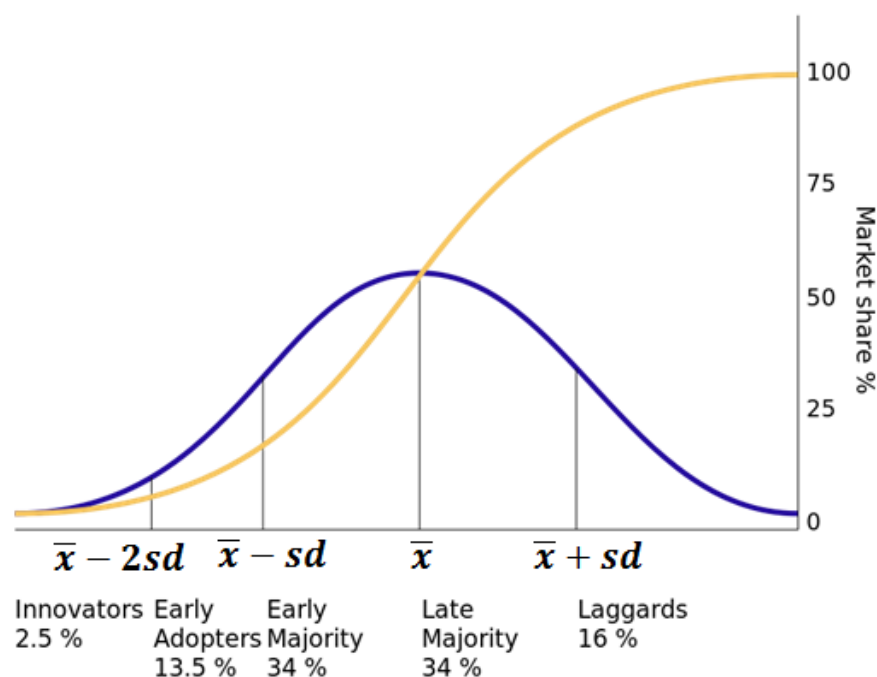
1. *Relative advantage* is the extent to which an innovation is regarded as superior to the previously used idea. Factors determining perceived relative advantage may be economic or social by nature, depending on the personality of adopter and the type of innovation.
2. *Compatibility* is the extent to which the innovation is persistent “with the existent values, past experience, and needs of potential adopters” (Rogers, 2003, p. 15).
3. *Complexity* is an attribute which describes the perceived difficulty of innovation usage. In contrast to other attributes of innovation, complexity is negatively correlated with the rate of adoption. High complexity is often an obstacle for the adoption of technological or technology-based innovations.
4. *Trialability* is an attribute which refers to the possibility of testing the innovation before making the adoption decision.
5. *Observability* is an attribute, related to the extent to which the outcomes of the innovation adoption can be visible to the other members of the social system.

Many empirical studies reported significant correlations between the attributes of innovation and the rate of adoption (e.g., Van Slyke, Belanger, & Comunale, 2004; Tornatzky & Klein, 1982; Tan & Teo, 2000). Apart from the factors described above, some authors distinguished additional attributes influencing the rate of innovation adoption. For example, Fliegel and Kivlin (1966) examined savings of time, savings of discomfort,

clarity of results, and pervasiveness, whereas Tornatzky et al. (1982) studied the impacts of innovation cost, profitability, and social approval.

### 2.2.3 Adopter categories

As it has been highlighted earlier, time is one of four main elements of innovation diffusion. Rogers (2003) explained the difference in the time of innovation adoption by adopters' innovativeness. He defined the innovativeness as the extent to which an individual is faster in adopting innovations in comparison with other members of a social system. The categorization of adopters on the basis of innovativeness, presented in Rogers (2003), implies five categories: innovators, early adopters, early majority, late majority, and laggards (Figure 2.2).



**Figure 2.2. Adopter categories (based on Rogers, 2003)**

For the adopter categorization, it is assumed that the distribution of the number of adoptions over time is approximately normal. The allocation of adopters into the groups is based on the statistics of the normal distribution – mean and standard deviation. The difference between the characteristics of adopters from the distinct categories is studied by many innovation researchers. For example, Brancheau and Wetherbe (1990) in their case study of spreadsheet adoption found that early adopters are typically younger and more highly educated, pay more attention to mass media, have larger communication networks, and are more probable to be opinion leaders. Similarly, Martinez, Polo, and Flavian (1998) concluded that younger people with better education tend to adopt innovations faster. They also found that gender affects the adoption rate of some innovations.

Apart from adopter categories, Figure 2.2 shows that the adoption of innovation follows the S curve when cumulative number of adopters is plotted over time. The curve rises slowly at first when the most innovative individuals adopt the innovation. Thereafter it

accelerates to the maximum rate when half of the potential adopters have adopted the innovative product. After that, the curve increases with decreasing rate when the smaller number of potential adopters remains. Finally, it reaches the saturation, when all the members of the social system interested in the innovation have eventually adopted it. Normal cumulative distribution function is not a sole model for describing the innovation diffusion. Mathematical modelling of the diffusion S curve is one of the central issues of innovation diffusion study. This question is discussed in more detail next.

## 2.3 Modelling the diffusion of innovation

One of the main objectives of innovation diffusion modelling is forecasting (Meade, 1984), which is defined as estimating “the proportion of relevant population that will have adopted innovation by time  $T + L$ , given the history of adoption up to and including time  $T$ ” (Meade & Islam, 1998). Innovation diffusion models can be generally classified into three groups: external influence models, internal influence models, and mixed influence models (Mahajan & Peterson, 1985). Section 2.3.1 explains the difference between these groups and presents mathematical models typically used for describing the diffusion of a new product. Section 2.3.2 introduces replacement purchase model, required for estimating the number of re-purchases, which often dominate the sales of mature diffused product.

### 2.3.1 First purchase diffusion models

External influence models refer to the type of diffusion models, which consider the influence of change agents as the only driver of innovation diffusion (Mahajan & Peterson, 1985). Often external influence is interpreted as the effect of mass media, but it has also been used for representing the impacts of government and regulatory, salespersons, and others. The general form of external influence model can be expressed as (Mahajan & Peterson, 1985; Kijek & Kijek, 2010):

$$\frac{dN(t)}{dt} = p(m - N(t)), \quad (2.1)$$

where  $N(t)$  is the cumulative number of adopters at time  $t$ ,  $\frac{dN(t)}{dt}$  is the rate of diffusion at time  $t$ ,  $p$  is the coefficient of innovation, and  $m$  is the saturation level, or potential number of adopters.

A classic example of the application of an external influence model is the study of Coleman, Katz, and Menzel (1966) who modelled the adoption of a new drug by doctors in four communities using the decaying exponential curve. The utilised model assumed that the information from the sources external to the social system was a sole driver of innovation diffusion, and the interaction between prior adopters and potential adopters did not attribute for any diffusion. This assumption clearly is not valid for the most of cases; thus, external influence models did not receive much attention in diffusion studies.

Internal influence models assume that diffusion of innovation occurs only due to interpersonal communication. Thus, the rate of the diffusion is defined as a function of social interactions between prior adopters and potential adopters, as equation (2.2) shows:

$$\frac{dN(t)}{dt} = qN(t)(m - N(t)), \quad (2.2)$$

where  $q$  is the coefficient of imitation.

The most widely used functions for modelling internal influence diffusion are logistic and Gompertz functions. Logistic function was first studied by Verhulst (1838) in relation to the population growth, but later has been often used for the modelling of diffusion of technological innovations (see Chu, Wu, Kao, & Yen, 2009 for review). Unlike symmetric logistic models, which reach the maximum rate of innovation adoption (inflection point) when the diffusion approaches half of the saturation level, Gompertz model (Gompertz, 1825) is asymmetric, and the rate of adoption is maximum when the innovation is diffused to about 37% of the saturation level. Even though internal influence diffusion models (particularly logistic and Gompertz models) are widely applied for estimating the diffusion of technological innovations, they do not consider the impact of change agents and therefore are not appropriate in the cases when influence of change agents is considerable.

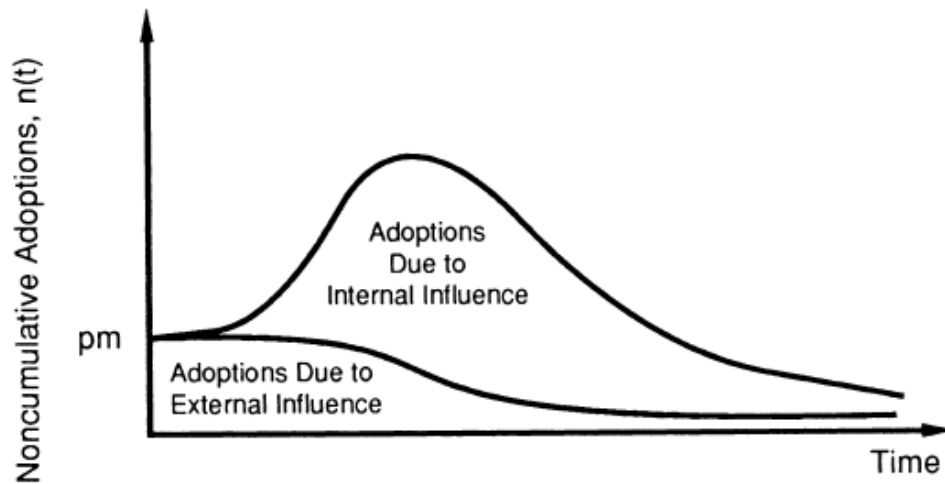
Mixed influence models are the most general group of diffusion models accounting for both internal and external factors of innovation diffusion:

$$\frac{dN(t)}{dt} = (p + qN(t)) \cdot (m - N(t)) \quad (2.3)$$

Bass (1969) developed a prominent mixed influence model known as the Bass Model which has received particular attention in diffusion forecasting literature. The Bass Model assumes that a social system where diffusion occurs is fully connected and homogenous. The model, in line with equation (2.3), further assumes that in a market with the potential  $m$  (potential number of adopters), two types of influences affect individual's decision to adopt the innovation: external influences represented by the coefficient of innovation  $p$ , and internal market influences related to the coefficient of imitation  $q$ . This idea is illustrated in Figure 2.3 (Mahajan, Muller, & Bass, 1990). Equation (2.4) describes the classical formulation of the Bass Model, as it presented in (Mahajan, Muller, & Bass, 1995):

$$\frac{f(t)}{1-F(t)} = p + q \cdot F(t) \quad (2.4)$$

where  $f(t)$  is probability of innovation adoption at time  $t$ ,  $F(t) = \frac{N(t)}{m}$  is cumulative fraction of adopters at time  $t$ , and  $\frac{f(t)}{1-F(t)}$  is the probability of adoption at time  $t$  given that adoption has not yet occurred.



**Figure 2.3. Adoptions due to external and internal influences in the Bass model (Mahajan et al., 1990)**

The Bass Model resulted in multiple extensions attempting to consider new circumstances of changing market reality. Bass (2004) in his commentary highlighted two important extensions to the original diffusion model: consideration of multiple product generations, and inclusion of decision variables in the diffusion model. Multigenerational diffusion model first proposed by Norton and Bass (1987) enabled the modelling of diffusion of technology's successive generations. The study showed that the market evolves from the earlier to later generations, expanding after each new successive generation. Another extension of the Bass Model, inclusion of decision variables, was first tested by Robinson and Lakhani (1975). They included the price of an innovation in the Bass diffusion model in order to investigate the optimal pricing for new products. Later modification, namely, Generalized Bass model (Bass, Krishnan, & Jain, 1994) enabled the inclusion of other decision variables, such as advertising.

The models described in this section are designed for the forecasting products' first purchases. However, as the product becomes more mature and diffused, purchased product units become worn out and outdated and eventually replacement purchases start to dominate total unit sales. Therefore, the focus moves to the forecasting of replacement purchases, as discussed next.

### **2.3.2 Replacement purchase model**

Replacement purchase forecasting model was first presented by Olson & Choi (1985) and Kamakura & Balasubramanian (1987). For the estimation of the number of replacement purchases, they calculated the number of product unit discards by considering the product unit service lifetime (replacement age) as a random variable following one of the probability distributions with the parameters which could be estimated based on the sales information (Kamakura & Balasubramanian, 1987), and the number of product units in the population (the latter is optional, see Kivi, Smura, & Töyli, 2012). Assuming that each

product unit discard leads to a replacement, the number of unit discards equals to the number of replacement purchases.

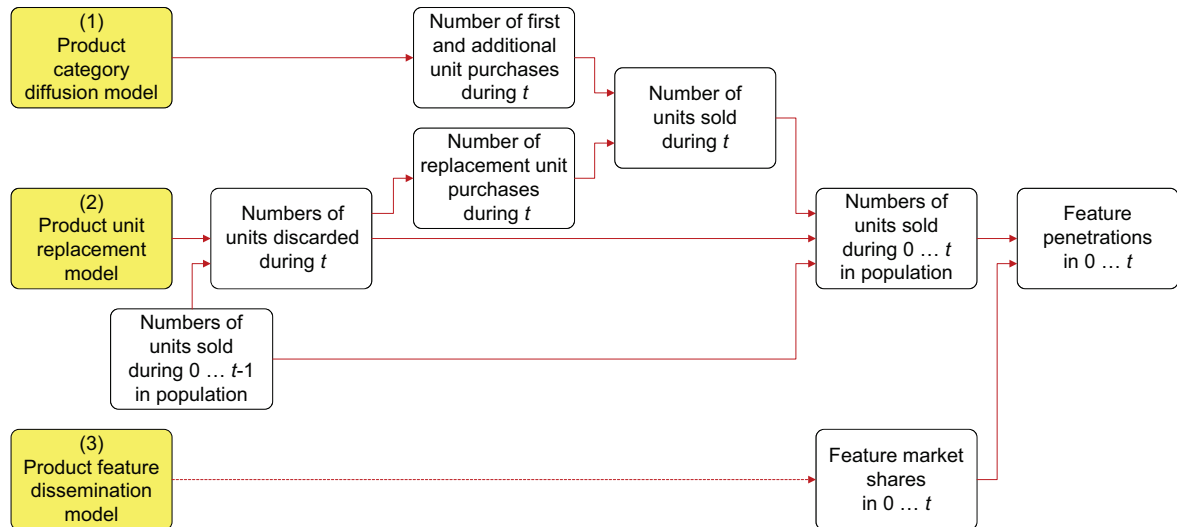
Addressing the problem of the estimation of product unit lifetime distribution, Islam and Meade (2000) studied the performance of a number of probability distributions including Triangular, Poisson, Rayleigh, Gamma, and Weibull, and concluded that none of them performed well in all or most circumstances. Therefore, forecasters typically test a number of distributions and choose the most appropriate one by the best fit to historical data. Having the lifetime distribution estimated, the number of discards can be calculated as follows (adapted from Kivi et al., 2012):

$$d_t = \sum_{i=0}^{t-1} s_i [F(t-i) - F(t-i-1)], \quad (2.5)$$

where  $d_t$  is the number of discards during time period  $t$ ,  $s_i$  is unit sales during the past time period  $i$ , and  $F(T)$  is cumulative probability function of unit lifetime distribution.

## 2.4 Diffusion of new product features

Focus of innovation diffusion studies is typically placed on the diffusion product categories. Some diffusion models attempt to describe adoption of successive generations of technology, others – take into account cross-country influences and effect of competition on innovation diffusion (see Peres, Muller, & Mahajan, 2010 for review). However, little attention has been paid to the diffusion of product components or product features even though the modelling of feature diffusion is increasingly relevant. To the author's best knowledge, one of the few works taking a systemic approach on modelling the diffusion of new product features is the study of Kivi et al. (2012). The study focuses on the diffusion of mobile handset features, although the proposed framework can be generally applied to the features of other durable goods.



**Figure 2.4. Product feature diffusion forecasting framework (based on Kivi et al., 2012)**

Figure 2.4 illustrates the logic of the product feature diffusion forecasting framework. The framework consists of three parts: product category diffusion model, product unit replacement model, and product feature dissemination model.

Product category diffusion model is used for the estimation of the first and additional unit purchases by fitting to historical data one of the sigmoid curve models described in Section 2.3.1. Product unit replacement model, in line with the discussion in Section 2.3.2, is based on the assumption of product unit lifetime. The article estimated the lifetime distribution based on the product unit discards. The number of discards, in turn, was calculated based on the number of product units in use, and the sales of product units using formula (2.6):

$$n_{m,t} = \sum_{i=0}^t (s_{m,i} - d_{m,i}), \quad (2.6)$$

where  $n_{m,t}$  is the cumulative sum of unit sales  $s_{m,i}$  and discards  $d_{m,i}$  during time periods  $0 \dots t$ .

The third model of the feature diffusion forecasting framework is a product feature dissemination model. Kivi et al. (2012, p.108) defined feature dissemination as “the planned and directed effort of product suppliers and regulators to affect the diffusion of product features”. The authors estimated previously unexplored phenomenon of feature dissemination using straightforward analogy-based extrapolation method. For each separate feature, future dissemination was estimated as an average of all trends of the other features that had passed the corresponding stage of the dissemination. If no analogy was found, the dissemination was assumed to stay at the prevailing level.

Generally, the forecasting framework of product feature diffusion presented by Kivi et al. (2012) has practical value: it considers primarily demand-driven forces (product category diffusion and product unit replacement) as well as primarily supply-side forces (product feature dissemination). Moreover, the model’s structure allows for meaningful sensitivity analysis. However, the framework has certain limitations: the dissemination model is based on simplistic method of forecasting by analogy; the unit lifetime distribution is assumed to be equal for different device models; the effects of complementary and substitute categories on product evolution and diffusion have not been taken into account. Nevertheless, the framework provides more accurate results in comparison with conventional sigmoid curve models, while being relatively simple and intuitively understandable.

### **3 Datasets and methods**

This chapter presents the description of datasets and methods used for the thesis research.

#### **3.1 Datasets**

##### **3.1.1 Mobile handset population**

Model-specific data on the number of mobile handsets was received from three Finnish mobile operators: DNA, Elisa, and TeliaSonera. The data was collected annually from 2005 to 2013 in the last week of September based on the charging functionalities of the mobile networks. Every time a subscriber makes a voice call, sends an SMS (Short Message Service), uses the Internet or produces any other type of traffic, network creates a charging data record (CDR) describing the chargeable network event generated by the user. Each CDR, among others, contains unique mobile device identifier - IMEI (International Mobile Equipment Identity). Research data was generated by counting the number of unique mobile devices (IMEI codes) and referring them to the mobile device models by using a part of IMEI code, called type allocation code (TAC).

After the installed base of active mobile device was received from each of three operators, the data was aggregated to the market level (Figure 3.1). Since the main focus of the analysis was placed on the diffusion of mobile handset features, all non-handset devices were filtered out from the aggregated mobile device base, forming market-level mobile handset base (or mobile handset population). The base covers 80-99% of all handsets in use in Finland depending on the year, with particular limitations. For example, some error could occur due to the missing data on the number of Apple iPhone in use in 2007-2010; mobile subscriber churn during observation period; minor differences in operator-specific data; unidentified devices and missing feature data of handset models; vagueness in definitions of some mobile device types, and other factors (Riikonen & Smura, 2013). However, the effect of the limitations was estimated to be small, therefore, the data accurately represent the Finnish mobile handset population.

##### **3.1.2 Mobile handset sales**

Model-specific data on mobile handset sales was provided by GfK (Gesellschaft für Konsumforschung - Society for Consumer Research), a market research company specialised in collecting retail data on technical consumer goods. The data represents monthly sales of mobile handsets in Finland from January 2003 to October 2013 and covers up to 90% of the retail market. In order to scale the data to full market coverage, information on quarterly handset sales was obtained from the collaboration forum of the Finnish consumer electronics and appliance industry KOTEK<sup>2</sup>. Hence, the sales volumes of all handset models from GfK were multiplied by the calculated scaling coefficient based on KOTEK data.

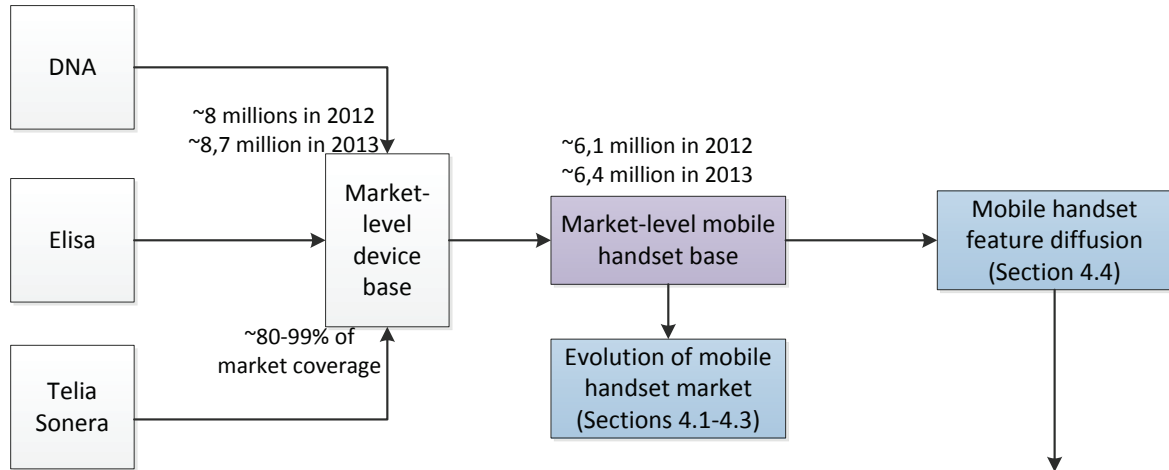
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<sup>2</sup> <http://www.kotek.fi/tilastot/>

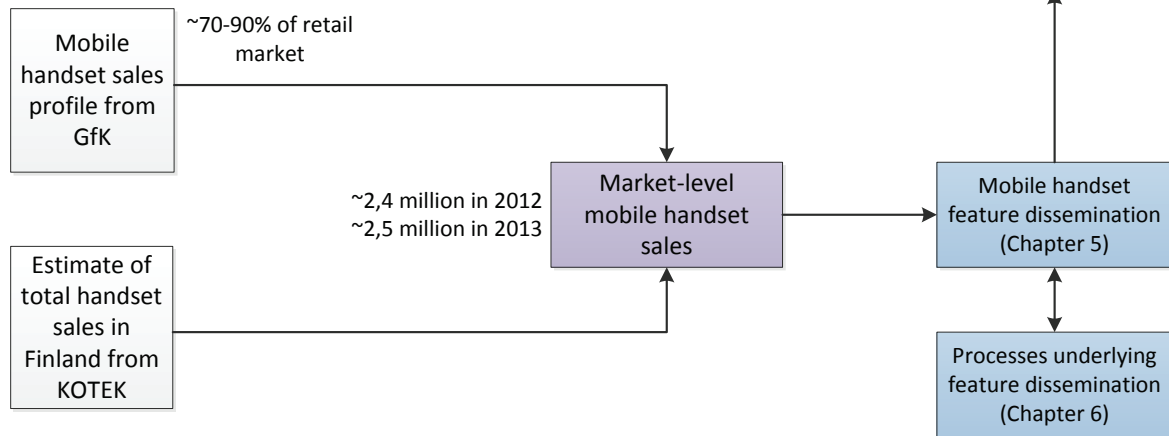


Apart from the sales data, GfK also provided the information on the technical components (features) included in every sold mobile handset model. In cases when the component (feature) information was missing from the received dataset, open sources, such as GSM Arena<sup>3</sup>, were used to fill the missing values. Figure 3.1 illustrates the use of the datasets in the analysis and provides the mapping of the datasets to the results of research presented in following chapters.

Annual data from 2005 to 2013 on model-specific number of active devices



Monthly data from 2003 to 2013 on model-specific mobile handset sales



**Figure 3.1. Datasets and analysis process**

## 3.2 Methods

This study utilises quantitative as well as qualitative methods of research. The former one is described in Sections 3.2.1 and 3.2.2, whereas the latter one is presented in Section 3.2.3.

<sup>3</sup> <http://www.gsmarena.com>

### 3.2.1 Descriptive analysis

Descriptive analysis is a method used for explaining the basic features of studied data. The focus of descriptive research is to gain understanding of the data and provide systematic description of the observed processes, organize the data and examine the relationship between variables (Frankfort-Nachmias & Leon-Guerrero, 2010).

Descriptive analysis is a logical starting point of a research. However, prior to the analysis, researcher should pre-process the data: find and treat outliers, missing values, impossible and atypical data points. Data pre-processing improves the quality of the dataset, and, as a consequence, decreases the probability of obtaining misleading results.

According to Frankfort-Nachmias and Leon-Guerrero (2010), descriptive analysis typically consists of five subsequent stages:

1. Organizing the data using frequency distributions
2. Displaying the data using graphic techniques
3. Indicating what is typical or average in a distribution
4. Finding variation in a distribution
5. Determining association between variables

Depending on the objectives of a descriptive study, researcher can prioritise some of the analysis stages. In the descriptive market research, particular attention is typically paid to organizing the data into the groups based on certain attributes and analysing the groups for gaining holistic understanding of the market evolution. When studying time series, identification of the trend, or the direction of long-term evolution is an important stage of analysis. The trend identification can be thought of as defining the relationship between the studied variable (for example, market share) and time, and, therefore, can be related to the fifth stage of the descriptive analysis process described by Frankfort-Nachmias and Leon-Guerrero (2010).

In this thesis descriptive research of mobile handset population in Finland is conducted in order to gain a better understanding of the market. The handset population bases, received from the mobile operators, are aggregated and pre-processed. The cleaned data is analysed for identifying the evolution of the shares of mobile device types, the leading mobile handset manufacturers, and smartphone operating systems. Furthermore, the historical patterns of mobile handset feature diffusion are studied and interpreted. The results of the analysis are presented in Chapter 4.

### 3.2.2 Dependency analysis

One of the central terms of the thesis is *feature interdependency*. Therefore, it is important to define this term for clear understanding of the focus area of the study.

**Definition 1.** *Two features A and B are interdependent if they are generally supplied and purchased in one bundle.*

Depending on the context and objectives of the research, different methods and metrics can be utilised for analysing the dependency between events. Taking into account the

definition of feature interdependency given above, association rule mining seems to be an appropriate method. Association rule mining is a well-researched and commonly used method for detecting the connections between variables in large databases (Agrawal, Imieliński, & Swami, 1993). Generally, association rule is an expression  $A \Rightarrow B$ , where  $A$  and  $B$  are sets of items, which can be thought of as the sets of mobile handset features in a given context. The meaning of association rules is intuitive: if a row  $R$  of a database contains a set  $A$ , then with a probability  $P$  it also contains a set  $B$  (Hipp, Güntzer, & Nakhaeizadeh, 2000). The probability  $P$  in association rule mining is referred to as *confidence* and can be defined as the following conditional probability:

$$\text{Confidence}(A \Rightarrow B) = P(B \in R | A \in R). \quad (3.1)$$

Even though association rule mining is practically significant in many application areas, it has two main problems. First, the computational complexity: the number of rules grows exponentially with the number of items. Second, only a small number of interesting rules needs to be selected out of the thousands of defined rules (Hipp et al., 2000). Therefore, in order to overcome these limitations, the process of association rule mining can be simplified by finding pair-wise association rules only. Confidence of the rule, as defined by equation (3.1), can serve as the measure of dependency between features  $B$  and  $A$ . Taking into account the definition of the confidence, and relatively narrow application area of this term, it has been decided to use the term “conditional probability” instead. Therefore, conditional probability has been selected as a metric of feature dependency in this study. Hereafter,

$$\text{Confidence}(A \Rightarrow B) = P(B \in R | A \in R) = P(B|A)$$

Conditional probability of event  $B$  given the occurrence of event  $A$  is defined as follows:

$$P(B|A) = \frac{P(A \cap B)}{P(A)}, \quad (3.2)$$

where  $P(A)$  is unconditional probability of the occurrence of events  $A$ ,  $P(A \cap B)$  is the probability of the intersection of events  $A$  and  $B$ , in other words, the probability of the simultaneous occurrence of events  $A$  and  $B$ . Conditional probability of event  $A$  given the occurrence of event  $B$ , analogically to (3.2), can be calculated as

$$P(A|B) = \frac{P(A \cap B)}{P(B)} \quad (3.2a)$$

Equations (3.2) and (3.2a) can be combined as follows:

$$P(A|B) \cdot P(B) = P(B|A) \cdot P(A) = P(A \cap B) \quad (3.3)$$

Dividing (3.3) by  $P(B)$ , Bayes theorem can be derived:

$$P(A|B) = \frac{P(B|A) \cdot P(A)}{P(B)}. \quad (3.4)$$

The definition of feature interdependency accepted in this study (definition 1), states that if features are *generally* bundled, they are considered to be interdependent. This definition can be expressed in terms of conditional probabilities. However, it is important to decide

which level of bundling can be considered as sufficient to define interdependency. Although this question is arguable, in this study features  $A$  and  $B$  are called interdependent if they are bundled in at least 90% of handset units equipped with the features  $A$  and  $B$  separately (**Definition 1a**):

$$P(A|B) \geq 0,9 \text{ AND } P(B|A) \geq 0,9$$

It should be noted that the accepted definition of feature interdependency differs from the conventional definition of dependent events. Two events are typically considered to be dependent if the occurrence of the first event changes the probability of the occurrence of the second event (Suh, 2012). In this study, although in the most instances this condition holds and the presence of feature  $B$  changes (more precisely, increases) the probability of the occurrence of feature  $A$ :  $P(A) < P(A|B) < 1$  and other way around  $P(B) < P(B|A) < 1$ , there might be cases where  $P(A) \approx P(A|B)$ , and  $P(B) \approx P(B|A)$ , but the features  $A$  and  $B$  are still viewed as interdependent as long as  $P(A|B) \geq 0,9 \text{ AND } P(B|A) \geq 0,9$ .

Furthermore, in some cases only one of the inequalities of Definition 1a holds. Then we conclude a one-sided or asymmetric dependency of the features (**Definition 2**):

*Feature  $A$  is asymmetrically dependent on the feature  $B$  if*

$$P(A|B) \geq 0,9 \text{ AND } P(B|A) < 0,9$$

One-sided dependency can be understood as follows: the presence of one feature (feature  $B$ ) entails the occurrence of another feature (feature  $A$ ) in at least 90% of cases, but at the same time, the presence of the latter feature (feature  $A$ ) implies the occurrence of the former feature (feature  $B$ ) in less than 90% of cases. Therefore, feature  $A$  is said to be asymmetrically dependent on feature  $B$ , consequently, feature  $A$  is called dependent, or affected; whereas feature  $B$  is called affecting, or influencing.

In order to calculate  $P(A|B)$  and  $P(B|A)$ , unconditional probabilities  $P(A)$  and  $P(B)$  of the events  $A$  and  $B$  should be known beforehand. When conducting repeated measurements with a large number of trials, frequentist interpretation of probability is useful. According to this approach, if the event is a subset of the sample space of the experiment, that is subset of a set of all possible outcomes, and only two possibilities exist for the event – it occurs or it does not occur, probability of the event occurrence can be calculated as a relative frequency of the event (see, for example, Bickel & Lehmann, 2012):

$$P(A) = \frac{N_A}{N}, \quad (3.5)$$

where  $N_A$  is the number of trials where the event  $A$  occurred, and  $N$  is the total number of trials.

Following the frequentist interpretation, the probability of the events' intersection can be calculated as follows:

$$P(A \cap B) = \frac{N_{A \text{ AND } B}}{N}, \quad (3.6)$$

where  $N_{A \text{ AND } B}$  is the number of trials where events  $A$  and  $B$  occurred together.

Furthermore, using equations (3.5), (3.6), and (3.2a), following formula can be derived for calculating conditional probabilities:

$$P(B|A) = \frac{N_{A \text{ AND } B}}{N_A} \quad (3.7)$$

The described methodology will be applied for measuring the degree of association between mobile handset feature dissemination for gaining a better understanding of this phenomenon. The term “feature dissemination” has been discussed before, but in the context of this quantitative study it is useful to define it in a slightly different manner (**Definition 3**):

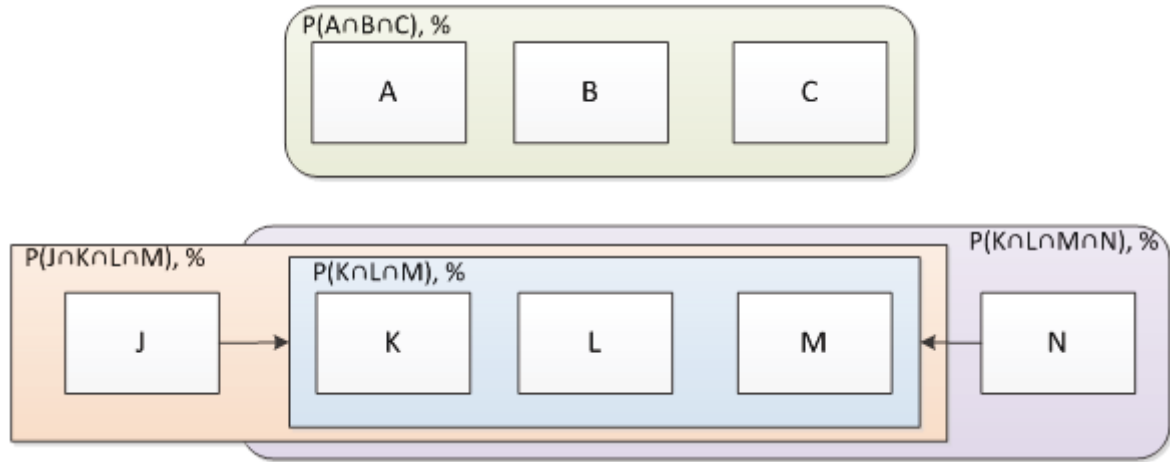
*Feature dissemination is the diffusion of a product feature in sales, i.e. the market share of product units equipped with the feature among all product units sold in time period  $t$ .*

Since we are concerned about investigating the relationships between the features in dissemination, the events of interest  $A$  and  $B$  are defined as follows:

$A$  – Feature  $A$  presents in a handset sold during time period  $t$

$B$  – Feature  $B$  presents in a handset sold during time period  $t$

Thus, in order to define the dependency between dissemination of two features  $A$  and  $B$ , we should calculate conditional probabilities between events  $A$  and  $B$ :  $P(A|B)$  and  $P(B|A)$ , using equation (3.7). The results of the calculations can be visualized as illustrated in Figure 3.2.



**Figure 3.2. Notations for representation the feature dependencies**

Let us explain the defined notations. Interdependent, or mutually dependent features which meet Definition 1a, are presented in the box without arrows between the features (e.g.,  $A, B$ , and  $C$ , or  $K, L$ , and  $M$ ). One-sided asymmetrically dependent features, compliant with Definition 2 are shown in the box with an arrow or arrows showing the direction of dependency (e.g.,  $K, L$ , and  $M$  depend on  $N$ , or  $K, L$ , and  $M$  depend on  $J$ ). It should be

further noted that the calculated dependencies are pair-wise. This means that if a feature set  $FS$  contains mutually dependent features  $A, B$ , and  $C$ , then:

$$P(A|B) \text{ and } P(B|A) \text{ and } P(A|C) \text{ and } P(C|A) \text{ and } P(B|C) \text{ and } P(C|B) \geq 0.9,$$

but it can appear that (example 1):

$$P(A \cap B|C) \text{ or } P(A \cap C|B) \text{ or } P(B \cap C|A) < 0.9.$$

The same applies for one-sided dependencies:

$$P(K \cap L \cap M|N) < 0.9, \text{ although}$$

$$P(K|N) \text{ and } P(L|N) \text{ and } P(M|N) \geq 0.9$$

However, in some cases, the intersection of the features also depends on the affecting feature (example 2):

$$P(K \cap L|M), P(K \cap M|L), P(L \cap M|K) \geq 0.9.$$

The same can be applied to one-sided dependencies:

$$P(K \cap L \cap M|J) \geq 0.9.$$

These two cases will have different notations. The former case (as in example 1) is presented by placing the features and the arrow (arrows) showing the direction of dependency (in case of asymmetric dependencies) in the box with rounded corners, whereas the latter case (as in example 2) is shown by placing the features and the arrows in the box with straight corners.

The notations also illustrate the market shares of the feature sets, calculated as:

$$P(FS) = P(\cap_{i=1}^n F_i) = \frac{N(\cap_{i=1}^n F_i)}{N}, \quad (3.8)$$

where  $FS$  is a feature set consisting of  $n$  features,  $F_i$  is the  $i$ -th feature in the feature set,  $P(\cap_{i=1}^n F_i)$  is the probability of the intersection of all  $n$  features of set  $FS$  in sold handsets in time period  $t$ ,  $N(\cap_{i=1}^n F_i)$  is the sales of the handset units equipped with all  $n$  features of the feature set  $FS$  simultaneously in time period  $t$ ,  $N$  is the total handset unit sales in time period  $t$ .

### 3.2.3 Expert interviews

Research interview can be defined as a conversation between two people with the aim of gathering relevant information for the purpose of research. Interview is a common method of qualitative analysis which helps researcher to “pursue in-depth information around the topic” (McNamara, 2014).

Qualitative interviews can be categorized in several ways. However, one common approach is to differentiate structured, semi-structured, and unstructured interviews (see, for example DiCicco-Bloom & Crabtree, 2006). In structured interviews questions are prepared beforehand and they cannot be changed during the interview. Typically structured interviews seek to test a priori hypotheses and produce quantitative data. In contrast,

unstructured interviews are designed for exploring meanings to generate new hypotheses. Unstructured interviews do not imply the presence of the list of predefined questions and can be considered as a guided conversation (DiCicco-Bloom & Crabtree, 2006). Semi-structured interviews are conducted based on the predetermined list of questions, however, unlike in structured interviews, other questions can emerge during the conversation.

This thesis adapts the method of semi-structured interviews. However, instead of the questions, the interviewer prepared a presentation with supporting materials and defined a list of topics to be discussed. Appendix A shows the defined interview topics together with examples of the asked questions.

Overall, seven one-hour interviews were conducted in May and June 2014. Table 3.1 presents the background information of the participated experts. Due to the reasons of confidentiality, the names of the interviewees are replaced by codes. The interview outcomes are analysed in Chapter 6.

**Table 3.1. Interviewees**

<b>Interviewee code</b>	<b>Organisation</b>	<b>Field of expertise</b>
<b>EDU</b>	Research institution	Professor, business simulation expert, business strategy instructor.
<b>HM1</b>	Handset manufacturing company; Research institution	Data analyst expert, expert of predictive modelling; PhD candidate
<b>HM2</b>	Handset manufacturing company	R&D, standardisation and industry collaboration expert.
<b>HM3</b>	Handset manufacturing company	Hardware expert
<b>HM4</b>	Handset manufacturing company	Consumer research marketing and software development expert.
<b>HMT</b>	Handset manufacturing and telecommunication companies	Product development, business and strategy management
<b>SC</b>	Semiconductor manufacturing company; Research institution	Software and hardware expert; PhD candidate

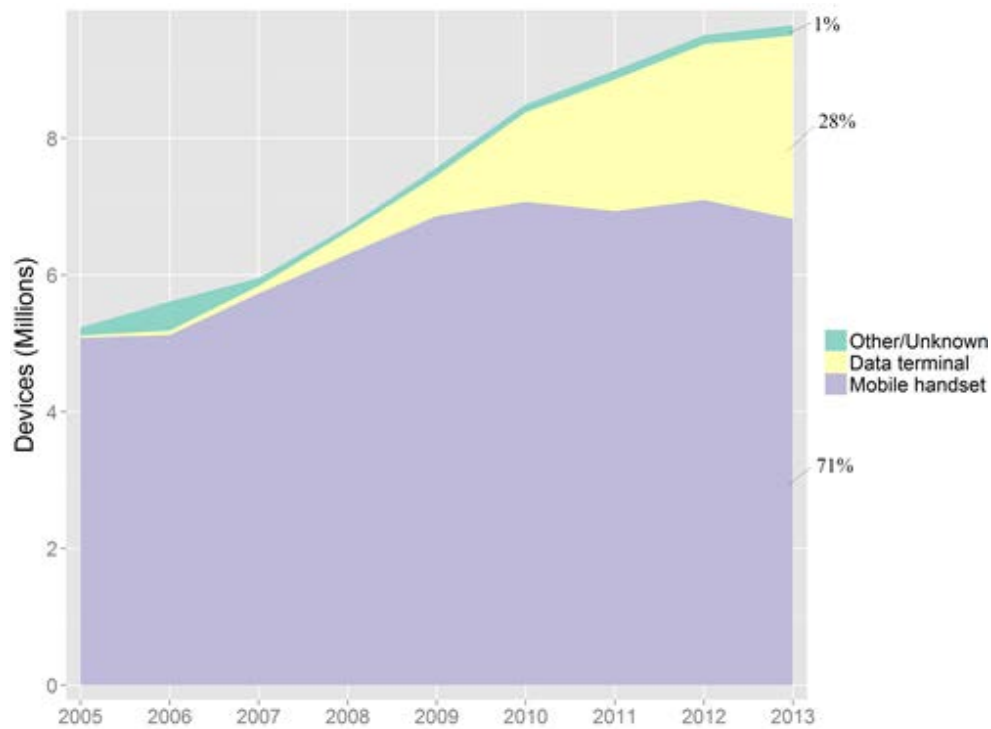
## 4 Evolution of mobile handset population in Finland

This chapter presents the results of quantitative study of mobile handset base evolution in Finland. Analysis of the handset population is necessary for detecting and studying the development trends of the mobile handset market. Understanding of these trends, in turn, is important prerequisite for improving the forecasting of mobile handset feature diffusion.

This chapter is organized as follows. Section 4.1 presents the shares of different device types in Finland. The phenomenon of the fragmentation of mobile handset population is investigated in Section 4.2. Section 4.3 discusses the evolution of mobile handset base by manufacturer and operating system. Finally, historical diffusion of mobile handset features is analysed in Section 4.4.

### 4.1 Evolution of the shares of mobile device types

Apart from growing technological advancement and economic affordability of mobile handsets, fast ICT progress enabled the usage of numerous communication devices for many different tasks other than voice calling. Thus, the trend of increasing number of data terminals can be seen in Figure 4.1.



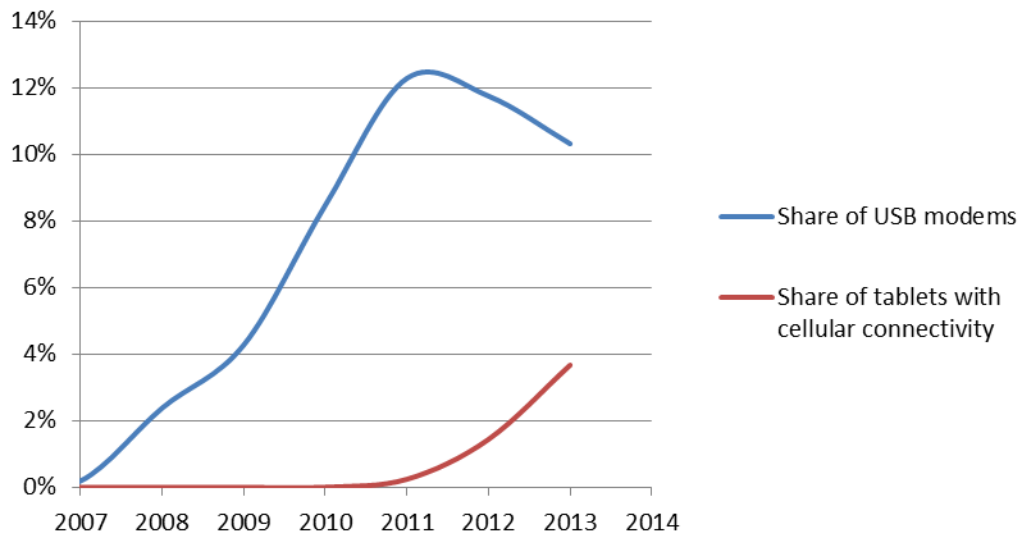
**Figure 4.1. Share of device types in Finnish mobile device population**

As the figure shows, the number of mobile handsets in Finland has stayed relatively stable for three years since 2010, accounting for about 6,9 to 7,1 million units. However, the share of mobile handsets has decreased because of the growth of the number of data terminals, which accounted for more than a quarter of all mobile devices in 2013. About 1% of all devices are “Other/Unknown”. Other devices are those types of devices which do



not belong to mobile handset and data terminal categories, for example, GSM desktop phones, SMS controlled power sockets, and car phones. The devices of unidentified types are considered to be “Unknown”. The share of unknown devices among “Other/Unknown” in 2013 was about 33% and therefore it did not introduce much inaccuracy into the analysis.

It should be further noted that “Data terminal” is an aggregated category, which includes, among others, tablets, USB modems, machine-to-machine (M2M) devices, game consoles, and laptops. M2M devices was the largest category among the data terminals in 2013, accounting for about 11,4% of the total number of cellular connections in Finland according to the study of GSMA (GSMA Intelligence, 2014) and our estimations. The second largest category of the data terminals in 2013 was USB modems; the evolution of its share is illustrated in Figure 4.2.



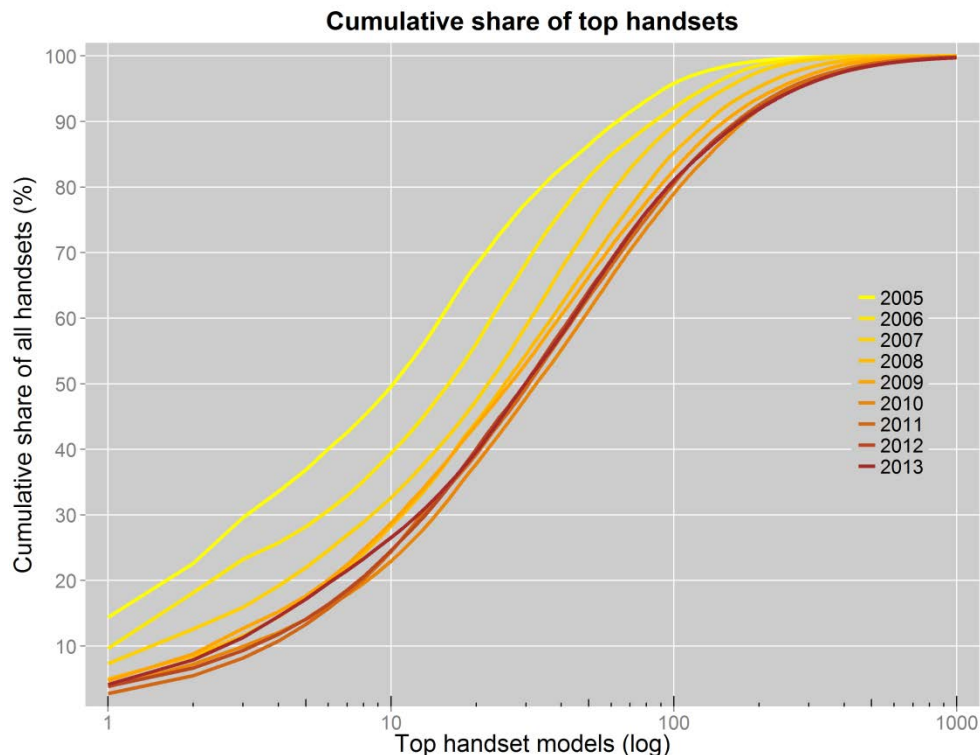
**Figure 4.2. Shares of USB modems and tablets with cellular connectivity in mobile device population in Finland**

The share of USB modems in Finland was the highest in 2011; afterwards, it started to decrease gradually and in 2013 was about 10%. The red line in Figure 4.2 illustrates the diffusion of tablets with cellular connectivity. The tablets started to penetrate Finnish device population in 2010, and after three years reached the diffusion level of about 4%. Tablet in the study is defined as “a small portable computer that accepts input directly on to its screen rather than via a keyboard or mouse” (Oxford Dictionaries, 2014); moreover, tablets are distinguished from smartphones by the absence of voice calling capability. It should be noted that due to the data collection method, it is not possible to take into account WLAN-only tablets, the share of which is about 66% of the total number of tablet computers according to the global estimates of Cisco (Cisco, 2014). Among the tablets with cellular connection, the share of different generations of Apple iPad in 2013 in Finland was about 57%, Samsung devices accounted for about 38% of the total number of tablets, and the rest 5% was produced by other manufacturers (including Sony, Huawei, Lenovo, and LG).

Overall, one trend of the evolution of device type shares in Finland is the increasing portion of data terminals, which can be mainly explained by the rapid growth of the number of M2M devices. First Mobile M2M devices emerged in the beginning of 2000s and provided very limited functionality. Contemporary M2M are becoming increasingly more complex, can include 3G, 4G and GPS connectivity, enabling new use cases such as a car, boat, and animal control, intelligent home appliances, or video surveillance systems. According to the report of GSMA Intelligence (GSMA Intelligence, 2014), Finland is one of the countries with the highest share of mobile M2M subscriptions among the total number of mobile subscriptions. It is expected that the number of M2M will continue to grow in the next several years. If the present growth rate of M2M devices continues, by the end of 2014, about 14,2% of devices in Finnish mobile networks will be M2M devices, whereas aggregated data terminals category will account for about 32% of the mobile device population.

## 4.2 Fragmentation of handset population

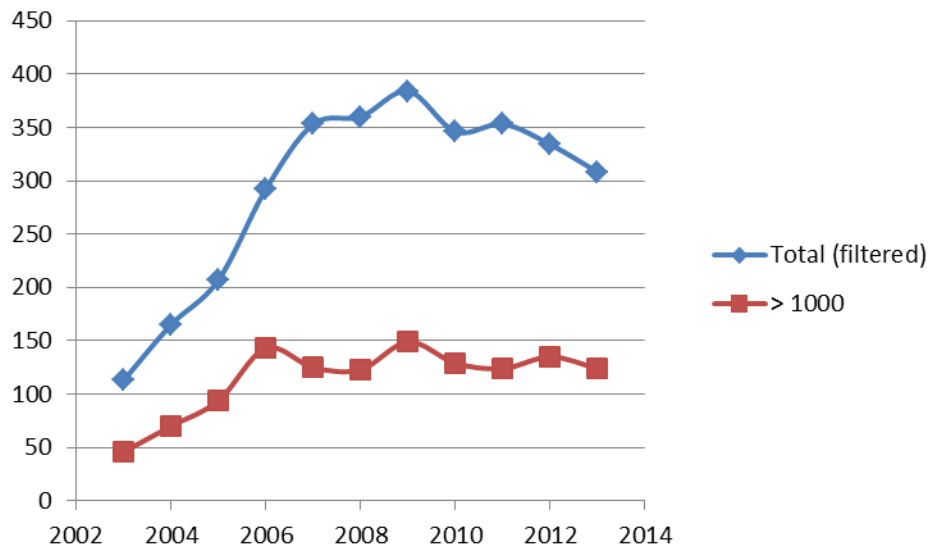
Fragmentation of handset population is a phenomenon describing a distribution of frequencies (shares) of handset models related to their ranks. Apart from considering individual shares of handset models, fragmentation can be also illustrated by plotting cumulative share of all models versus their ranks, as shown in Figure 4.3.



**Figure 4.3. Fragmentation of handset population in Finland**

The most significant changes in the fragmentation of handset population in Finland occurred during 2005-2007. One of the reasons for this can be a fast growth of the number

of handset models in sales during that period of time. As can be noticed in Figure 4.4, in 2003-2007 the number of handset models in sales in Finland increased threefold, whereas starting from 2007, it has stayed relatively stable. It should be noted that out of all offered handset models (blue line in Figure 4.4), only about one third appear to be successful with the sales of 1000 units and more in one year (red line in Figure 4.4).



**Figure 4.4. The number of handset models in sales**

The increase in the number of offered mobile handset models can be associated with several possible factors. One reason is industry maturation and technology advance, which enabled producing more handset models with different features and styles addressing various customer segments. Another reason is increasing competition partly due to the entrance of new market players (HTC, Huawei, ZTE), which resulted in a greater number of handset brands and models.

### 4.3 Manufacturer and operating system shares

Figure 4.5 presents the evolution of the shares of mobile manufacturers in handset population in Finland. The share of the largest manufacturer Nokia declined from 72% to 63%, while the portions of Samsung and Apple rose from 15% to 20% and from 6% to 10% respectively. The shares of Sony/Ericsson and HTC in 2013 were about 1%, and Doro – a manufacturer of handsets for senior citizens – accounted for about 2% of the total number of handsets in Finland. The group of “Others” manufacturers (3% in 2013) was represented, inter alia, by LG (0,7%), Huawei (0,4%), and ZTE (0,3%).

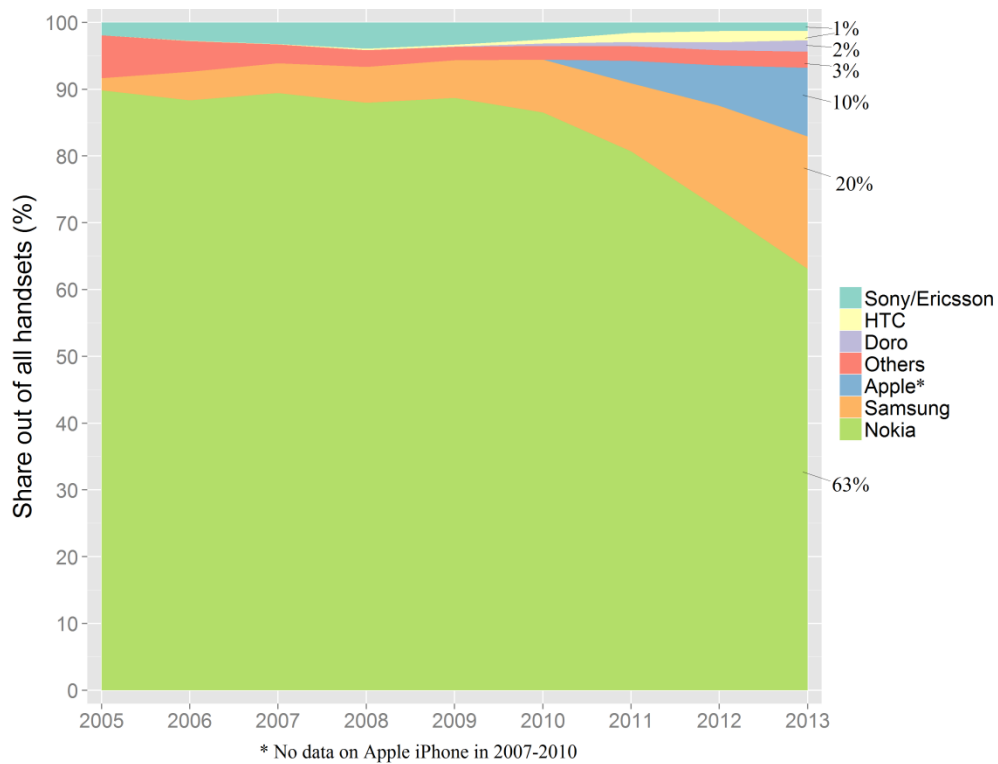


Figure 4.5. Mobile handsets in use in Finland by manufacturer

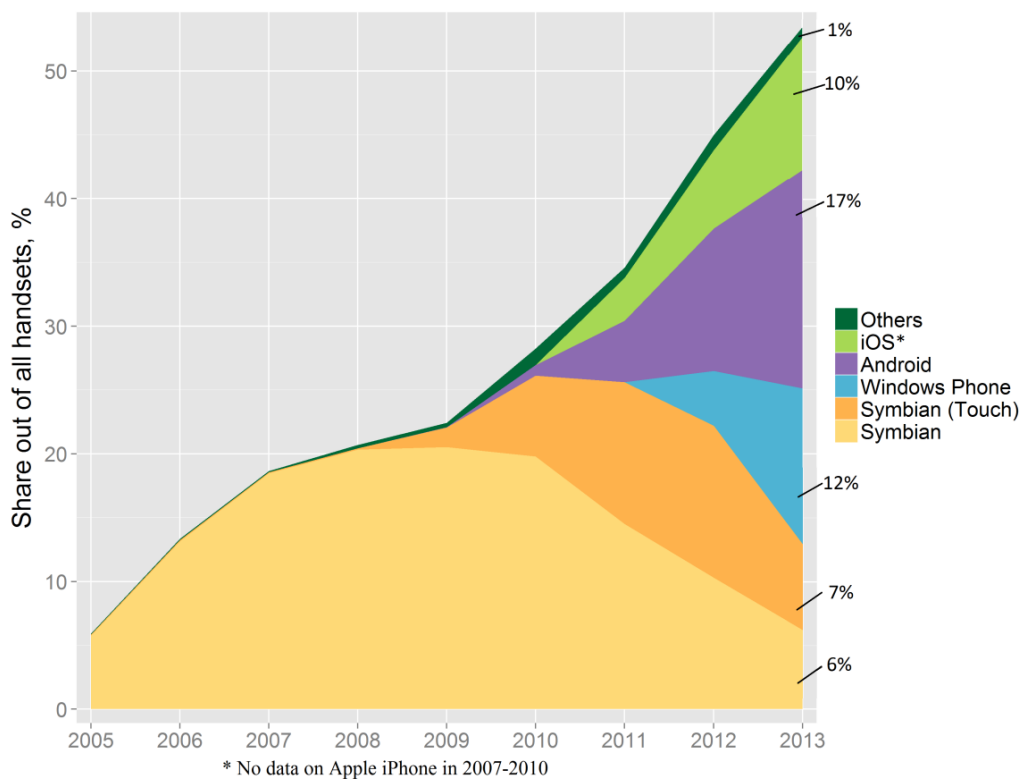


Figure 4.6. Smartphones in use in Finland by operating system

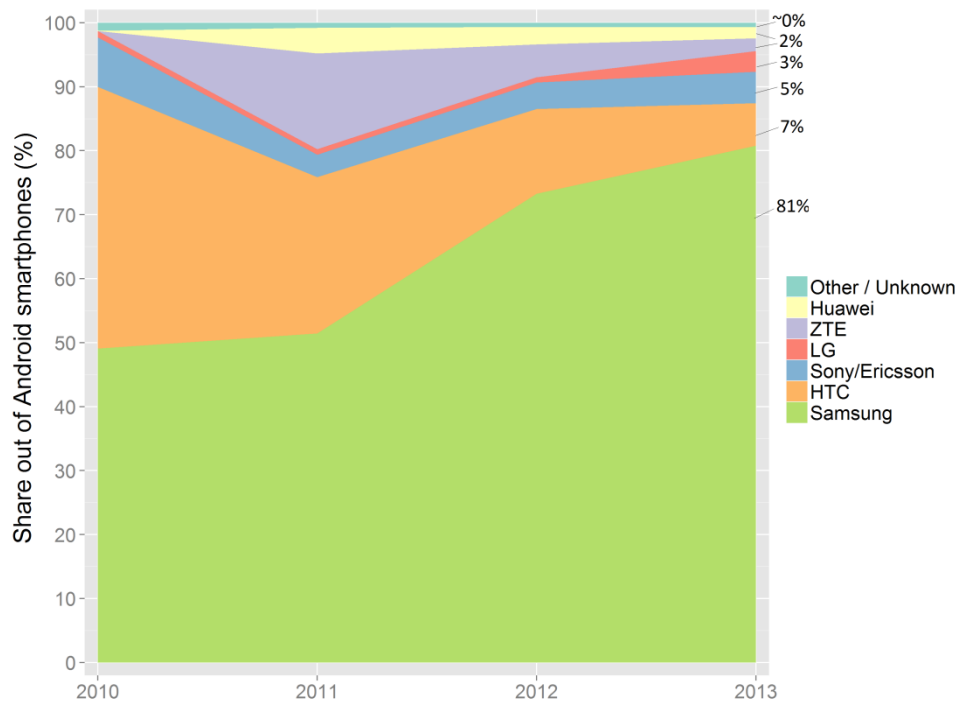
With the course of evolution of the mobile handset market, as smartphones start to account for an increasingly large share of mobile handset population, it becomes more relevant to study the shares of smartphone operating systems instead of analysing the shares of handset manufacturers. For a start, it is important to define the term “smartphone”. Although slightly different definitions exist, we understand the smartphone *as a mobile handset with possibility to install a third party application* (**Definition 4**). Therefore, the handsets running Android, iOS, Windows Phone or some other operating systems are counted as smartphones. Figure 4.6 shows the evolution of mobile handset population in Finland by operating system.

The share of smartphones (53%) in handset population in Finland in 2013 for the first time exceeded the share of mobile phones (47%). Windows Phone demonstrated the most significant growth of the share, from 4% in 2012 to 12% in 2013 (the growth rate about 200%). The shares of iOS and Android also increased: from 6% to 10% (growth rate about 67%) and from 11% to 17% (growth rate about 55%) respectively. The portion of Symbian OS in 2013 decreased considerably from 22% to 13% (the rate of decrease about 41%). Taking into account that almost all Windows Phone and Symbian handsets in the population in Finland are produced by Nokia (about 99% and 100% respectively), it can be said that the share of Nokia smartphones in 2011-2013 has stayed relatively stable, about 25-26%.

The only smartphone series running iOS is Apple iPhone. In September 2013 the most popular Apple smartphone models were iPhone 4S (37% out of all iPhones in handset population in Finland), iPhone 4 (32%), iPhone 5 (26%), and iPhone 3GS (5%). However, it should be noted that research data does not cover the time after the official start of sales of iPhone 5C and 5S models.

The most popular smartphone OS in Finland in 2013 was Android, which has surpassed Symbian for the first time. In contrast to the smartphones running iOS and Windows Phone, which are produced primarily by Apple and Nokia respectively, Android-based smartphones are represented by a variety of handset manufacturers, as illustrated in Figure 4.7.

In 2013 Samsung was the leading producer of Android smartphones with the share increased from 73% to 81% out of all Android handsets. At the same time, the portion of Android smartphones produced by HTC declined from 13% in 2012 to 7% in 2013. The shares of other Android phone manufacturers – Sony/Ericsson, LG, ZTE, and Huawei have varied from 2% to 5%.

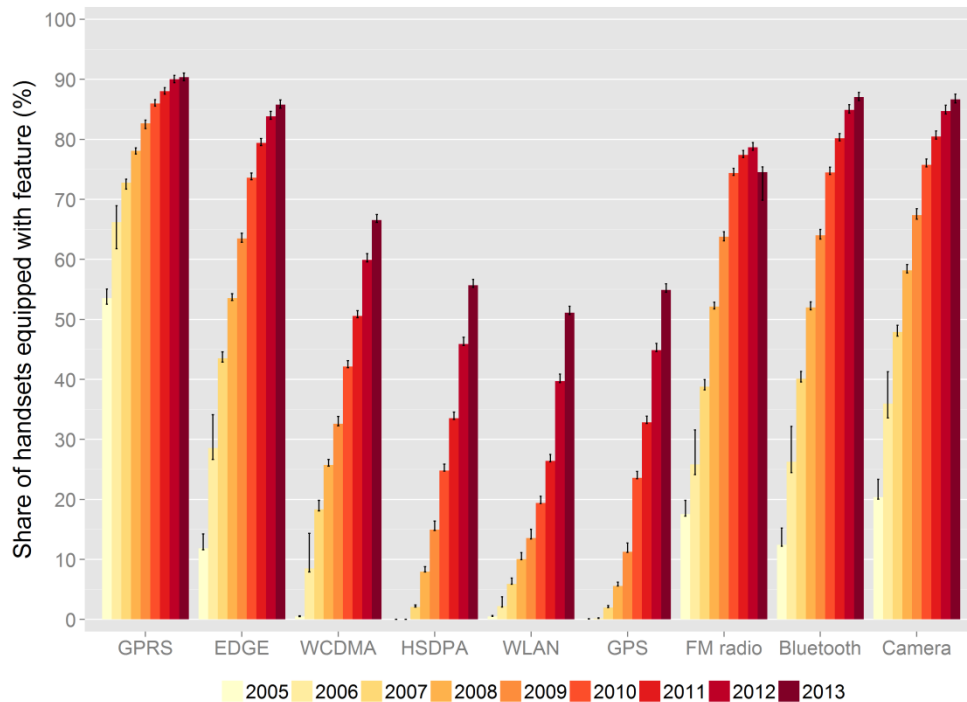


**Figure 4.7. Shares of Android smartphones by manufacturers**

It can be observed that the evolution of mobile handset base in Finland can be roughly divided into two time periods: before and after 2010. The first period is characterized by Nokia's leadership in the number of sold handsets and in operational results (Deidu, 2010). The transition from the first to the second period began in mid-2008, when the first iPhone sales started in Finland. Later, in mid-2009, the first Android devices became available to the local market. However, at that time Nokia failed to compete in this emerging smartphone race. This resulted in the decrease of its share in 2010 and marked the beginning of the second period of handset base evolution. Trying to maintain the market share, at the end of 2011, Nokia launched the first model from Windows Phone-running Lumia smartphone series. However, as the analysis shows, the share of Nokia's devices in handset base in Finland continued to decline even after the launch of Lumia smartphones. Nevertheless, the tendency can change since the share of Nokia Lumia series in Finland has been increasing rapidly in 2011-2013.

#### **4.4 Historical diffusion of mobile handset features**

Figure 4.8 illustrates historical diffusion of nine selected mobile handset features. The error bars indicate possible errors due to the unknown devices or handsets with unidentified feature presence.



**Figure 4.8. Diffusion of mobile handset features in 2005-2013**

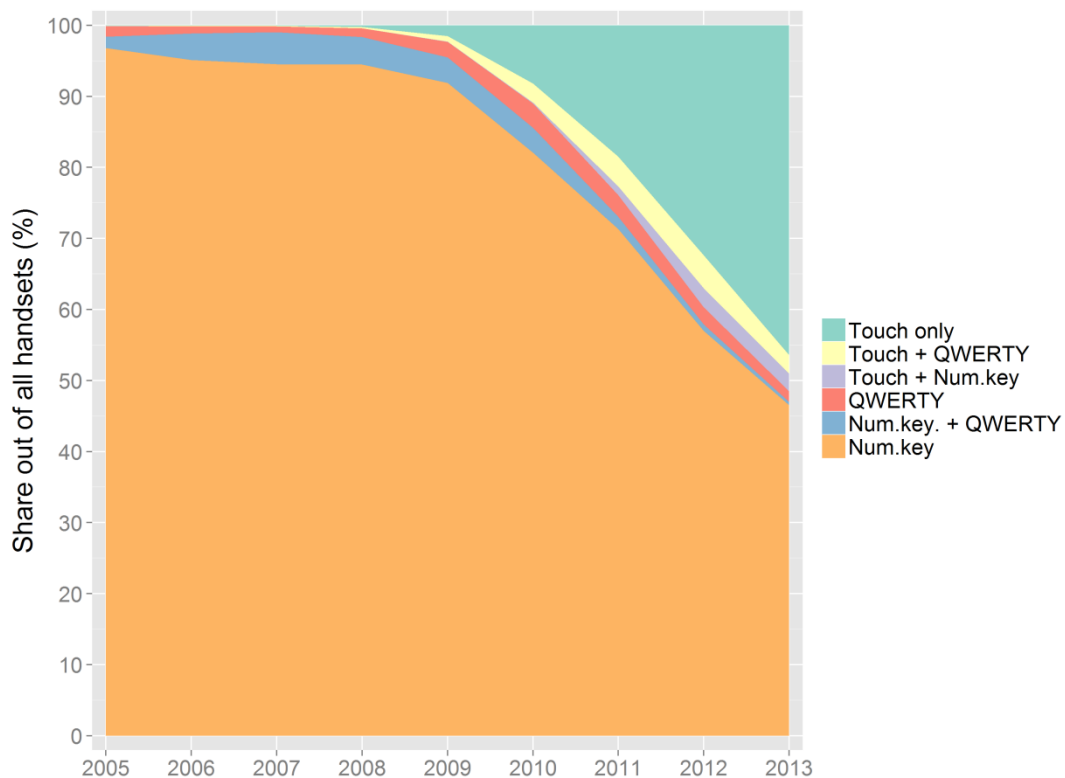
The figure allows identifying typical phases of the diffusion process which can be particularly noticed on the examples of HSDPA, WLAN, and GPS. First, one can observe the phase of early slow adoption after the introduction of a feature (e.g., the increase in the penetration of WLAN in 2006-2007 was about 4%), which is followed by the period of rapid growth (e.g., the increase in the penetration of WLAN in 2011-2012 was about 14%). The saturation phase can be noticed from the patterns of diffusion of mature features such as GPRS, EDGE, Bluetooth, and Camera in the latter 2-3 years (e.g., the increase in the penetration of GPRS in 2012-2013 was about 0,05%). Notable, that the level of saturation of the four mentioned mature features is about 90%, which means that about 10% of all handsets in Finland do not have basic Internet connectivity as well as camera and Bluetooth.

As the figure shows, the only feature with decreasing level of diffusion in 2013 was FM radio (79% in 2012 → 75% in 2011). This can be explained by the absence of the feature in some popular high-end models, including Samsung Galaxy S4, and all generations of iPhones.

Diffusion of recently introduced features LTE (Long Term Evolution) and HSPA+ in the end of 2013 was on the early stages. First LTE-enabled handsets were sold in Finland in 2012, and one year later the diffusion of LTE increased from 0,1% to 7%. Remarkable that the diffusion of NFC (Near Field Communication) started before 2005, but its estimated share in 2013 was still between 10% and 15%. Generally, analysing the diffusion of NFC, two adoption waves can be noticed: the first with the peak in 2006 when the share of NFC

increased to almost 7%, and the second, started in 2011, when the diffusion of NFC began to grow after 4 years of declining.

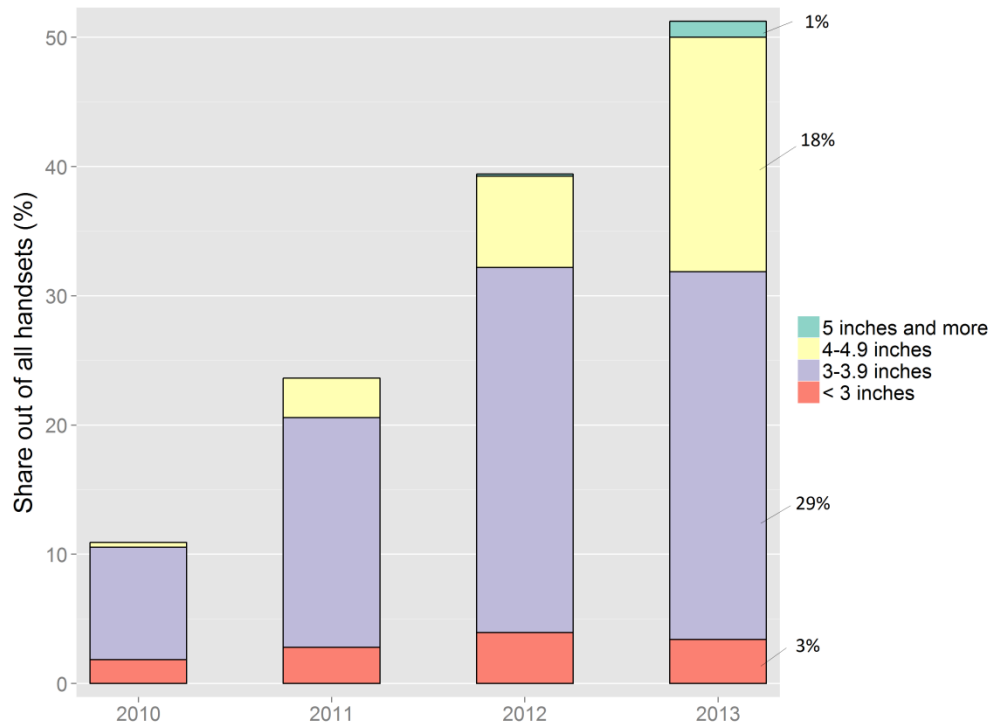
Apart from the introduction of new handset features, mobile handset evolution can be also characterized by the changes in the most common input methods. As can be seen in Figure 4.9, until 2009, a numerical keypad was the only prevailing method of input. However, in 2009 after the beginning of smartphone revolution, marked with the introduction of first iOS and Android smartphones, touch screen handsets started to diffuse rapidly and substitute handsets with the numerical keyboard. In 2013 the share of devices with a touch screen as the only input method increased from 32% to 46%. Moreover, considering mobile handsets with the touch screen as one of the two alternative input methods, the diffusion of the touch screen devices in 2013 was 51%. The share of multitouch in 2013 was 42%. Multitouch can be defined as touch screen capable of recognizing two or more points of contact on the surface concurrently (GSM Arena, 2014).



**Figure 4.9. Shares of input methods in handset population**

Another ongoing trend in the evolution of mobile handsets is the increasing size of touch screen displays, as shown in Figure 4.10. Thus, the share of 4-4,9" touch screen devices in 2013 increased from 7% to 18%, whereas the share of smaller 3-3,9" touch screen handsets stayed relatively stable, about 28-29%.





**Figure 4.10. Shares of touch screen sizes**

Summarizing, it is evident that the evolution of handsets can be characterized by several trends: the increasing number and affordability of handset features (and as a consequence their increasing penetration), the growing number of smartphones and devices with the touch screen input, and the increasing display sizes in the touch screen devices. In the evolution of smartphones, another notable tendency is improving computing characteristics. For example, HTC Dream (the first Android smartphone) released in 2009 was equipped with a single-core 528 MHz CPU, whereas Samsung's flagship Galaxy S5 introduced in 2014 has a quad-core 2,5 GHz CPU. As a consequence, in order to control decreasing battery lives resulting from the growing energy consumption of higher-performance smartphones, manufacturers include batteries with larger capacity in new smartphone models. In the above mentioned handset models, battery capacities are 1150 mAh and 2800 mAh respectively.

## 5 Dissemination of mobile handset features

This chapter focuses on studying the dissemination of mobile handset features in Finland quantitatively. Section 5.1 describes historical patterns of feature dissemination, whereas Section 5.2 considers interdependencies between dissemination of mobile handset features.

### 5.1 Historical patterns of dissemination

As has been defined earlier, feature dissemination corresponds to the market share of product units equipped with the feature among all the product units sold during the time period  $t$ . Figure 5.1 shows the dissemination of mobile handset features in Finland. The figure was built based on the aggregated yearly sales data.

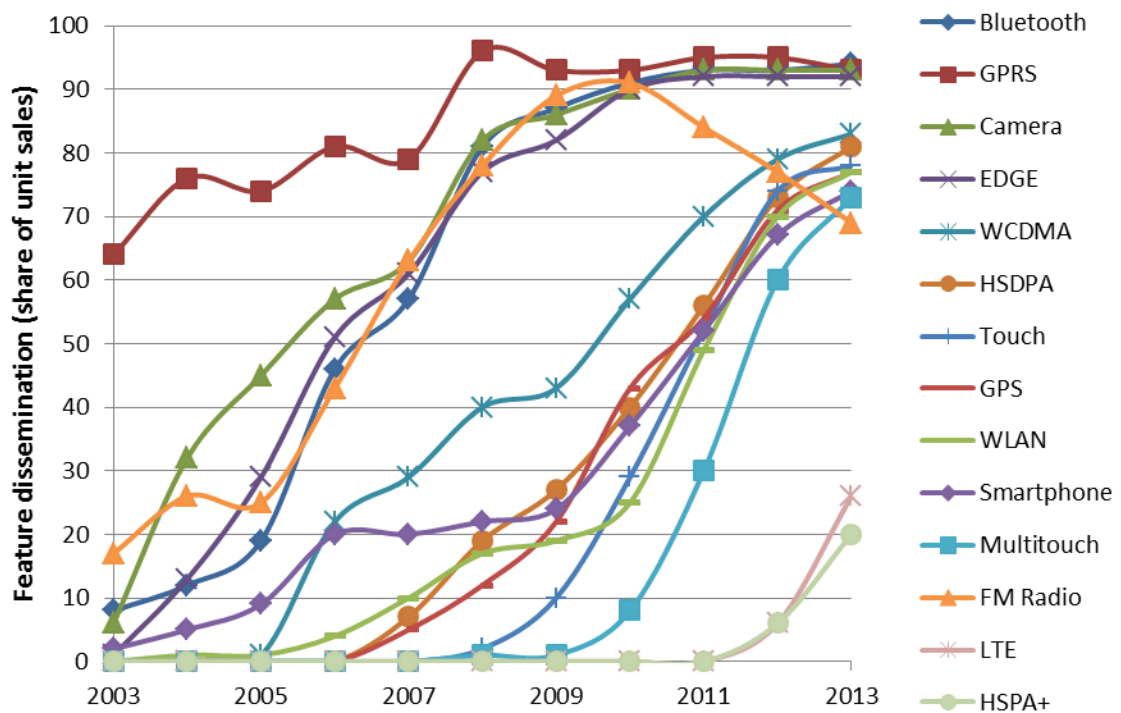


Figure 5.1. Dissemination of mobile handset features in 2003-2013

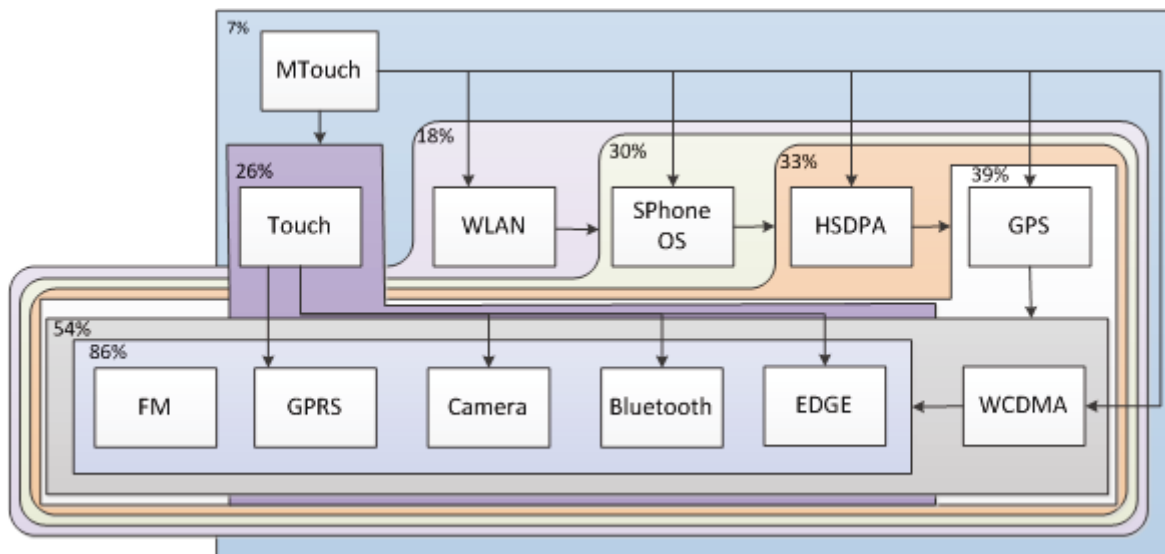
As the figure shows, dissemination of GPRS, Bluetooth, Camera and EDGE have reached saturation at the level about 93%. The dissemination of other features except FM radio in 2013 continued to grow, although the penetration of some components in sales increased only slightly approaching the saturation level (for example, WCDMA in 2012-2013 increased from 79% to 83%).

The dissemination of FM radio has been decreasing rapidly since 2010, falling from 91% in 2010 to 84% in 2011, 77% in 2012, and 69% in 2013. Effect of this decline on the feature's diffusion can be seen in Figure 4.8 (Section 4.4); however, while the dissemination of FM radio started to drop in 2010, the first decrease in the feature diffusion happened in 2013. This illustrates the slowness of a handset replacement process.

As can be noted in the figure, the patterns of features' dissemination are not random. Visually it is possible to define several groups of the features which disseminate in similar ways. One group is Bluetooth, GPRS, Camera, and EDGE, which have had roughly the same market shares in sales starting from 2010. Another example is the bundle of HSDPA, Touch, GPS, WLAN, and Smartphone OS in 2011-2013. In order to increase the reliability and the accuracy of the feature diffusion forecasting model, dependencies of the features' dissemination should be studied in more detail. Section 5.2 addresses this question and provides the quantitative evidence of the existence of mobile handset feature interdependencies.

## 5.2 Feature interdependencies in dissemination

The analysis of feature dependencies in dissemination presented in this section is conducted based on the methodology described in Section 3.2.2. Let us first test connections between the features in 2010. This year is considered because it is the last year before new smartphones started to penetrate Finnish market on a large scale: in 2010, the aggregated share of iOS and Android devices in sales was about 6,5%, whereas in 2011 it increased to 23,5%. Figure 5.2 illustrates the diagram of feature interdependencies in handset sales in 2010.



**Figure 5.2. Diagram of feature dependencies in handset sales in 2010**

The figure shows a hierarchical structure of the features in sales: in 2010, multitouch (MTouch) was the least disseminated and the most technologically advanced feature, so that its presence increased the probability of occurrence of the other considered features except FM to at least 90%. The next feature in the hierarchy was WLAN followed by Smartphone OS, HSDPA, GPS, and WCDMA (Figure 5.2). Based on this structure, it can be concluded that in 2010 the presence of additional features was an important factor of the differentiation of various handset models and target categories.

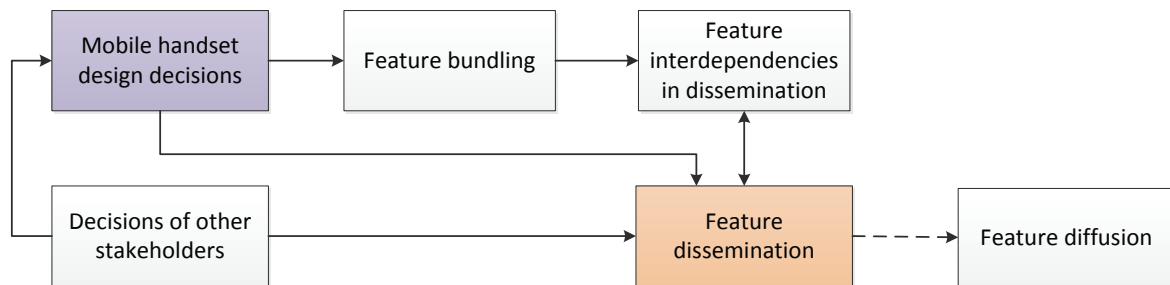


Overall, these two figures illustrate the interdependent patterns of feature dissemination and the dynamic nature of interdependencies between them. Moreover, the figures show that features are supplied in bundles. Logically, handsets of different price categories include various feature bundles. For example, whereas GPRS and Bluetooth can be observed in low-end handsets, high-end devices include LTE and NFC together with GPRS and Bluetooth. Because of this, the diagrams illustrate hierarchical structure of the features and feature bundles. The phenomenon of feature dissemination is further studied qualitatively based on the expert interviews in Chapter 6.

## 6 Study of mobile handset features dissemination

This chapter describes the results of the semi-structured presentation-based industry expert interviews which were conducted in May and June 2014 in order to reveal the processes underlying mobile handset feature dissemination. The topics discussed during the interview are presented in Appendix A, and the list of interviewees is given in Section 3.2.3.

In general, mobile handset feature dissemination is a process primarily controlled by handset manufacturers. It should be noted, however, that the decisions of some other stakeholders can also affect feature dissemination. Nevertheless, general understanding of the feature dissemination process can be obtained from studying mobile handset design decisions. Therefore, it is assumed that uncovering the design process of mobile handset models directly leads to the understanding of feature dissemination phenomenon (Figure 6.1).



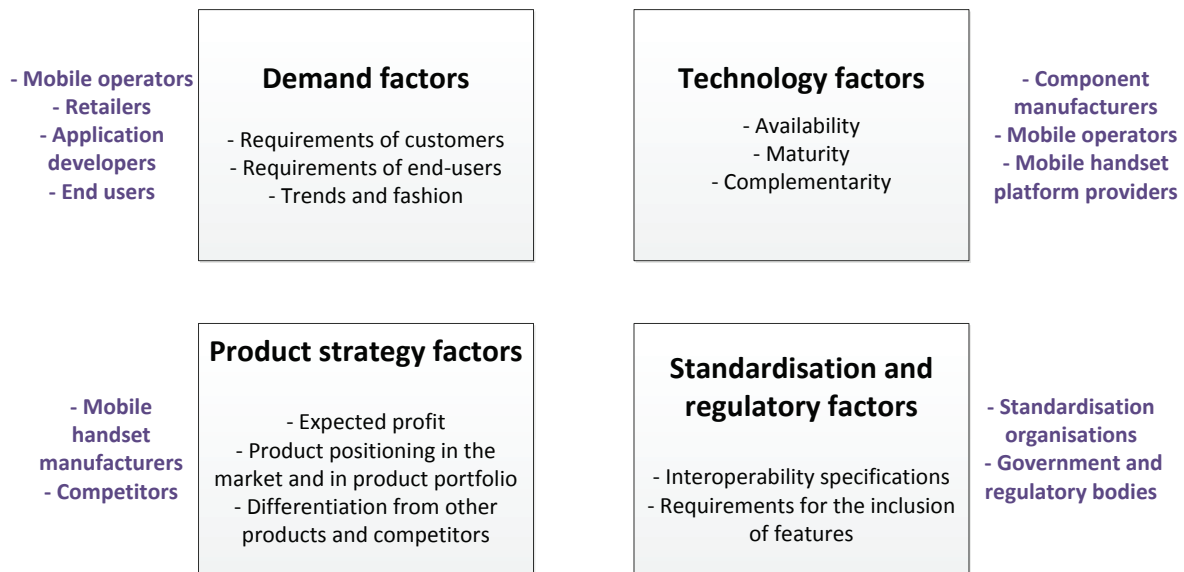
**Figure 6.1. The impact of mobile handset design decisions on feature dissemination and diffusion**

### 6.1 Factors affecting mobile handset design decisions

After the interviewees were explained the details of the research and the validity of Figure 6.1 was checked, they were asked to evaluate a preliminary conceptual model of the factors affecting decisions made on the design of new mobile handset models and suggest whether to include new groups of factors or remove unnecessary ones. All seven experts evaluated the model as being precise and closely mirroring reality.

The final model based on the experts' comments is shown in Figure 6.2. Mobile handset design decisions are influenced by four groups of factors: demand, technology, product strategy, standardisation and regulatory factors. The actors related to each group of the factors are shown on the left or on the right side from the corresponding factor group.

Apart from evaluating the conceptual model, the experts were also asked to provide concrete examples of the cases showing the effects each group of factors can have on mobile handset design decisions. The factors together with the illustrative examples are discussed in more detail in Sections 6.1.1– 6.1.4.



**Figure 6.2. Factors affecting mobile handset design decisions**

### 6.1.1 Demand factors

Consumer demand and needs are critical for the development of new mobile handset models, as well as other products. **HMT** noted that mobile manufacturers conduct numerous consumer studies in order to elicit end users' needs and preferences in different countries. When developing new handset models, manufacturers need to consider the market differences: while in some Asian markets a large display is treated as the most important feature, the majority of European users do not value it that much.

Assessing the impact of technology and market-related factors (i.e. the question of technology push and market pull), **EDU**, **HM3**, and **HMT** agreed that technology-related factors prevail in introducing innovative mobile handset features, because a typical handset user is not able to explicitly express his demands and expectations of future mobile handset models. **HM4**, in turn, stated that both technology and market factors are important for introducing innovative features. Market pull approach is necessary for satisfying users' needs and making small incremental improvements, whereas technology push drives mainly larger innovations needed for the purpose of differentiation from competitors.

Apart from the end-user requirements, demand factors include the needs of mobile operators and application developers, along with trends and fashion. Thus, **EDU** noted that the operators' opinion must be considered in a way that cellular companies are willing to subsidise the handset sales and provide a distribution channel for the handset manufacturers. Although the impact of the cellular operators on mobile manufacturers is more profound in the US than in other markets (**EDU**), due to globalisation, the decisions of large American operators also affect the design of mobile handsets for other markets, including Finland (**HM3**). A prominent example of the carriers' impact on the feature dissemination was provided by **SC**. According to him, in 2004, American mobile operators rejected the idea of selling handsets with touch screen displays because they did not

believe in its superiority over devices with a conventional physical keyboard. Furthermore, **HM3** noted that when the first mobile devices equipped with WLAN started to appear, mobile operators did not want to sell them because the operators were afraid of losing mobile internet traffic, and, as a consequence, service profits. However, with the rapid growth of the amount of mobile data traffic and the spread of flat-rate fees, mobile operators got interested in offloading the traffic to Wi-Fi networks to solve the problem of congestion.

According to **HM4**, application experience is a primary factor affecting whole mobile ecosystem. Therefore, the requirements of the largest application developers must be considered while designing new mobile handset models. **HM4** told that if the developers of popular applications such as Facebook or Instagram introduce in collaboration with one mobile manufacturer a new function enabled by an additional sensor, the other handset manufacturers will have to include the sensor in order to enable the same capability and not to lose in face of tough competition. **HMT** agreed with the claim of **HM4**, but noted that mobile handset manufacturers will be ready to include a new sensor only if the functionality enabled by it can substantially improve the experience of the application usage.

Another demand factor, trends and fashion, define a direction of a product evolution for a particular period of time. Examples of the historical trends of mobile handset evolution are miniaturization and emergence of different handset form factors such as clamshell and slider (**EDU**). Illustrating the importance of the trends and fashion, **EDU** provided the example of Nokia's failure in estimating the popularity of clamshell phones, which resulted in the company's revenue and market share losses. The effect of the trends on mobile handset design decisions is acknowledged by all seven interviewed experts. **HMT** noted that it is particularly important to recognise the trends when designing handsets for the youth. However, as **HM1** explicitly mentioned, the estimation of trends and fashion is difficult. **HM3** commented that some of handset manufacturers are working on the development of flexible handsets, but this is difficult and requires substantial investments.

Overall, prior to designing a new handset model, mobile manufacturers collect and analyse the requirements of end-users, large mobile manufacturers and retailers, as well as application providers. Particular attention is typically paid to the differences in markets and customer segments: one feature can be critically important for the end-users in one country for one customer category, whereas the same feature can appear much less relevant in another country for different group of customers. While listening to the opinion of customers carefully, handset manufacturers also introduce technology-driven innovations, because customers can rarely formulate their expectations to the new handset models precisely. Handset manufacturers also detect and follow the emerging trends in the design of mobile handset models. Moreover, creating a market trend is a big success for a handset manufacturing company.



### 6.1.2 Technology factors

Technology factors have a significant impact on the design of new handset models. It is obvious that handset functionality is constrained by available technologies; thus, its evolution requires continuous technological progress which can be achieved by substantial investments in research and development. Considering that mobile handset is a complex electronic device, development of an innovative mobile handset model requires substantial efforts and R&D investments not only from mobile manufacturers, but also from other stakeholders of the ecosystem. In this context, component producers play a particularly important role. As **HM4** and **HMT** noticed, for the introduction of an innovative feature, a corresponding electronic component (chip or circuit) have to be developed in at least 2-3 years prior to the feature's launch.

Furthermore, all seven interviewees acknowledged the importance of technology maturity and complementarity for the development of new handset models. However, sometimes manufacturers hurry to be the first to the market with a new feature, and ignore the level of technology maturity and the availability of necessary complements. As an illustration, **EDU** considered the following example. In 1999, Finnish mobile manufacturer Benefon introduced the world's first handset model equipped with the GPS navigator (GPS feature). However, despite the novelty of the idea, the navigation capability was not able to provide satisfactory user experience because of the feature's immaturity and the lack of the complements (maps, high-quality screens, fast Internet connection, sufficient capacity of memory and processing power). Therefore, the diffusion of GPS did not take off until the moment when the feature became mature enough and the navigation in mobile handsets became practically usable.

The case of NFC, which started to appear in mobile handsets in early 2000s, but failed to diffuse into a standard, is another example of the feature immaturity according to some of the experts. NFC is a communication standard intended for use in contactless payments as well as in short-range communication, as a substitute to Bluetooth. **EDU**, **HM4**, and **HMT** explained the fail of NFC in 2000s by the absence of real use cases. However, **EDU** noted that the feature can eventually take off and become common for smartphones. **HM2** and **HM3** were more sceptical about the success of the NFC. They said that NFC does not provide better experience in comparison with conventional card payments and, moreover, requires collaboration between many stakeholders (banks, credit card companies, retailers, and handset manufacturers), which is difficult to achieve in practice.

Overall, technology factors play essential role in the design of new mobile handsets and in the dissemination of handset features. First of all, in order to implement a new function, necessary technologies must be available and corresponding chipsets must be ready. However, the availability of technology is not a sole requirement for the feature success; in order to diffuse, technology must be mature and essential complements must be available in order to provide good user experience.

### 6.1.3 Product strategy factors

According to Business Dictionary (2014), product strategy is a plan for marketing a product that is based on the analysis of anticipated profit and competition. Clear product strategy defines the product positioning in the market and in the company's portfolio and must be developed prior to the launch of the new product into the market, already at the stage of the product design.

Discussing the product strategy factors, **HMT** noted that one of the important steps in the process of a new handset model design is preliminary estimation of the product's profitability. The expert told that product management teams in handset manufacturing companies have to reach the compromise between the features which are included in the handset and its cost, so that the manufacturers can achieve the planned gross margins given the estimated retail price of the handset. Considering that inclusion of a new feature in the handset causes the increase in its cost, the innovative features are more probable to appear in high-end handsets rather than in simple feature phones. This is because the buyers of advanced smartphones are more willing to pay for extra features than the users of cheaper phones. Thus, all the seven interviewees agreed that a typical approach to the launch of the new mobile handset feature is top-down: the feature is first introduced in high-end handsets, then, when the production of the feature component becomes cheaper, it appears in mid-end and low-end devices.

Furthermore, **HM2** noted that while deciding whether to include a feature in a handset model or not, together with the component cost, mobile handset manufacturers also take into account the cost of feature's usage, which is borne by the customers. Thus, even though LTE chip can eventually become cheap enough to be included into the lower-end handsets, it may appear to be useless for the target users unless the price of the LTE service becomes affordable for them. Moreover, in many cases the infrastructure availability is another decisive factor of equipping the handset model with the feature (**HM2, HM3**). Indeed, if the infrastructure is unavailable, it is senselessly to add to the handset model LTE, HSPA+, NFC or other features which require the infrastructure for functioning.

Differentiation is another aspect of the product strategy which is essential for its success (**HM1**). It is natural that a new handset model has to introduce something new in comparison with the older ones, but it has also to differ from the products offered by competitors. In face of tough market competition and market maturity, mobile handset manufacturers invest large amount of money in R&D activities in order to innovate and differentiate from the competitors. Indeed, the differentiation is often a key to a success, but sometimes attempts to distinguish the product from the others end in failure. For example, Nokia's N-Gage handheld gaming platform became a failure (Osborne, 2005) despite its novelty and the difference from competitors' offerings.

Overall, product strategy factors to a great extent affect the design of mobile handset models and feature dissemination. First of all, the most of handset models are developed in a way that the bill of materials and the expected retail price allow achieving certain gross margin. Thus, if a feature component is costly and its price does not decrease, the feature

will probably fail to diffuse to a high level because it is not feasible to include it into the mid-end and low-end models. However, typically the price of the components drops substantially due to the competition and the effects of economy of scale. The diffusion of innovative features starts from the high-end handsets also because the manufacturers want to encourage customers to buy more expensive handsets. Furthermore, differentiation is a critical factor affecting characteristics of handset models. The differentiation requires substantial investments in R&D, but it does not guarantee the success of a new product.

#### **6.1.4 Standardisation and regulatory factors**

Standardisation is a process of developing standards in order to ensure compatibility and interoperability between separate products or whole system (Blind, 2014). Standards are typically developed by standardisation organizations, which allow all relevant players express their opinion regarding the direction of future industry evolution (Costa-Pérez et al., 2013). Therefore, standardisation can be understood as the self-regulation of an industry (**HM2**). Regulation, in turn, is a set of rules typically issued by a government, designed to control certain processes, goods or services. While standardisation is defined at the industry level, regulations usually vary from country to country. Mobile handset production is a subject to particular standardisation and regulation.

Most of mobile phones in the world operate in the networks according to specifications defined by 3GPP - 3rd Generation Partnership Project. 3GPP standards include GSM, GPRS, EDGE, WCDMA, HSPA, and LTE, and encompass radio, core network, and service architecture (3GPP, 2014a). Apart from the 3GPP standards, the handsets equipped with WLAN, are subject to IEEE 802.11 specifications developed by the Institute of Electrical and Electronics Engineers. Furthermore, the handsets with the Internet connectivity must be compliant with the IETF (Internet Engineering Task Force) standards. Since new technologies and procedures are standardised typically a couple of years before the technology is finally implemented in a commercial product, the standards can serve as indicators of the mobile phone future evolution. For example, LTE Advanced was specified by 3GPP Release 10 in the first half of 2011 (3GPP, 2014b), whereas the first commercial LTE-A network and handset appeared two years later (Telecom Paper, 2013). On the other hand, the first handset compliant with 802.11ac was launched when the standard had not yet been approved. Moreover, according to **HM2**, in some rare cases the standardised technology or feature can fail and be rejected by the market.

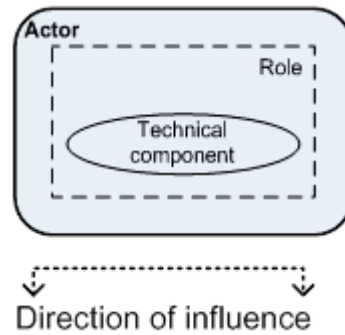
Regulation is a set of rules needed for implementing particular policies. For instance, maximum limitation of Specific Absorption Rate (SAR), regulated in many countries, is intended for protecting users' health from harmful electrical and magnetic radiation. Whereas some regulations are common for many countries, some others are country-specific. For example, Enhanced 911 directive issued by Federal Communications Commission in the USA obligates manufacturers to equip handsets with the GPS capability; whereas another FCC regulation states that at least one third of manufacturer's handset models must meet hearing aid compatibility requirements (**HM3**; FCC, 2014). As **HM4** and **HMT** noted, some countries have especially strict regulation rules, as, for

example, China. According to **HMT**, Chinese government requires manufacturers to include certain features (e.g., local version of WCDMA) in mobile handsets or pay a penalty if the required components are missing from the device models. Discussing the market regulation in Finland, the experts were able to mention the only example of mandatory unbundling of mobile handsets and mobile services, which was discontinued in 2006 in order to accelerate the diffusion of 3G (discussed in Tallberg, Hämmäinen, Töyli, Kamppari, & Kivi, 2007).

Overall, standardisation plays an important role in the design of new mobile handset models. Since standardisation is needed in order to ensure compatibility between the products, new features typically have to be standardised before their introduction into mobile handsets. This especially applies to the features which require infrastructure for functioning. Depending on the region, regulation can also greatly affect the mobile handset design, and feature dissemination. Some countries strictly require from manufacturers to include particular features in order to obtain permission to sell mobile handsets, whereas some others allow the absence of the feature, but require paying penalties. However, the experts did not provide any examples of the regulation of mobile handset production and sales in Finland.

## **6.2 Value network of mobile handset industry**

Each group of the factors affecting mobile handset design decisions and feature dissemination can be related to specific actors. For example, demand factors can be associated with the end users, retailers, and mobile manufacturers, whereas technology factors can be linked with the component producers, application developers, and application platform providers. For better understanding of the main industry stakeholders and their roles in the processes of mobile handset development and production as well as feature dissemination, it is important to analyse a value network of the industry. Since smartphones account for the most of mobile handsets population and sales, it is more relevant to analyse the value network related to the smartphones rather than feature phones. Although these two value networks are similar in many ways, a major difference is the existence of a mobile platform, which is the basis for smartphone operation. Depending on the platform, two different value network configurations can be identified: a vertically integrated value network relevant for the smartphones running iOS and Windows Phone, and a horizontal value network, applicable in the case of Android-running smartphones. Among many methods of illustrating the value network, this study selected notations of Casey et al. (2010) with some modifications, as depicted in Figure 6.3.



**Figure 6.3. Notations of value network representation (based on Casey et al., 2010)**

During the interview, experts were asked to evaluate pre-defined industry value networks and suggest addition or removal of the stakeholders or changes to the structure. Figure 6.4 represents vertically integrated value network of the industry, improved based on the interviewees' comments. Generally, vertical integration refers to the strategy of getting ownership or increased control over suppliers or distributors in order to increase the firm's market power (Strategic Management Insight, 2014). In the value networks of smartphones running iOS and Windows Phone, mobile handset platform provider plays several roles, namely, mobile platform operation, mobile handset production, application store operation, and to some extent sales of mobile handsets. Therefore, the value network of iOS and Windows Phone smartphones is referred to as vertically integrated.

Horizontal value network, in contrast, does not imply a single stakeholder controlling hardware, software, and related services. This kind of value network is depicted in Figure 6.5 and can be observed in case of Android running smartphones. A platform provider is responsible for the operation of the platform and application store, whereas handsets are produced and sold by a separate actor (handset manufacturer). It should be noted that some Android-based smartphones do not utilise the app store managed by the mobile handset platform provider. For example, Nokia created a separate official application marketplace for its Android-running Nokia X series. Moreover, some other examples do not fit the value networks depicted below. For instance, Finnish handset manufacturer Jolla runs Sailfish OS which is declared to be compatible with Android hardware and applications (Bhushan, 2013). However, these examples account for a small share of the smartphone market and, therefore, are not considered in this study.

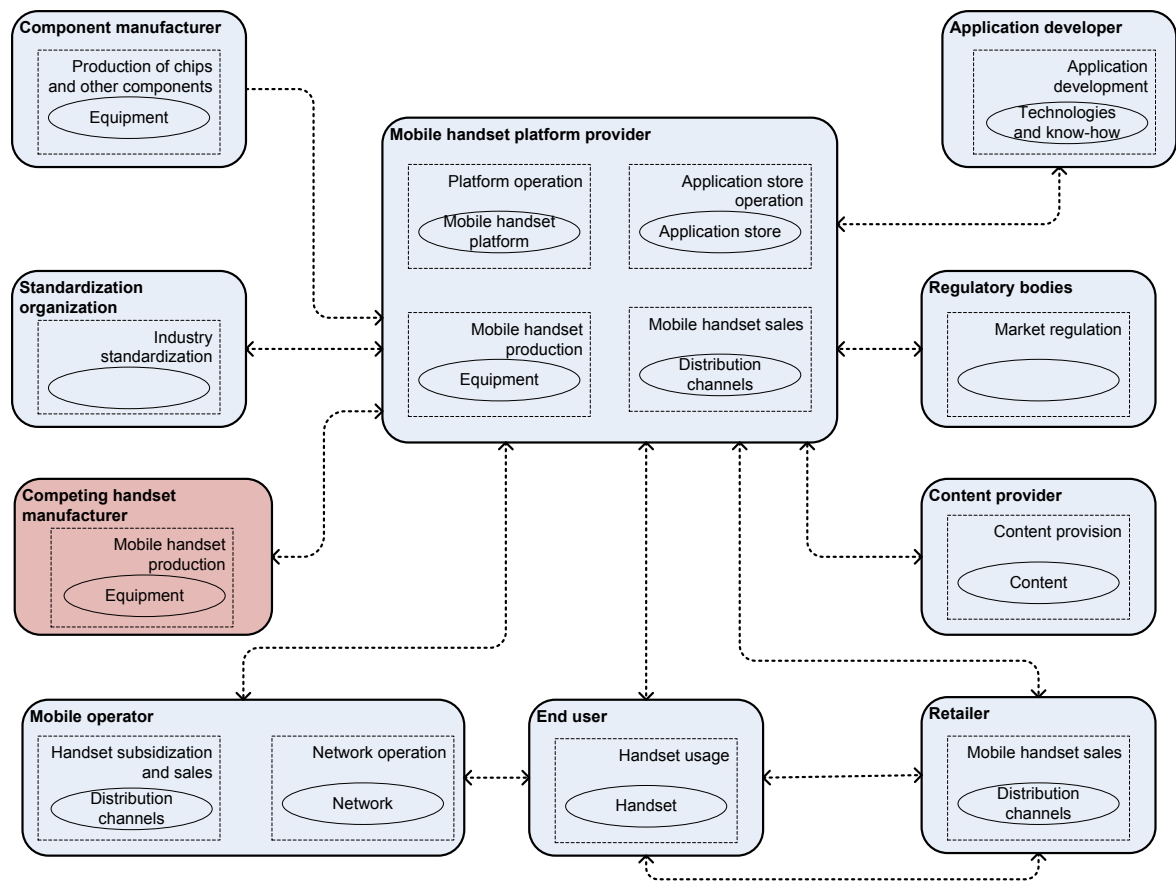
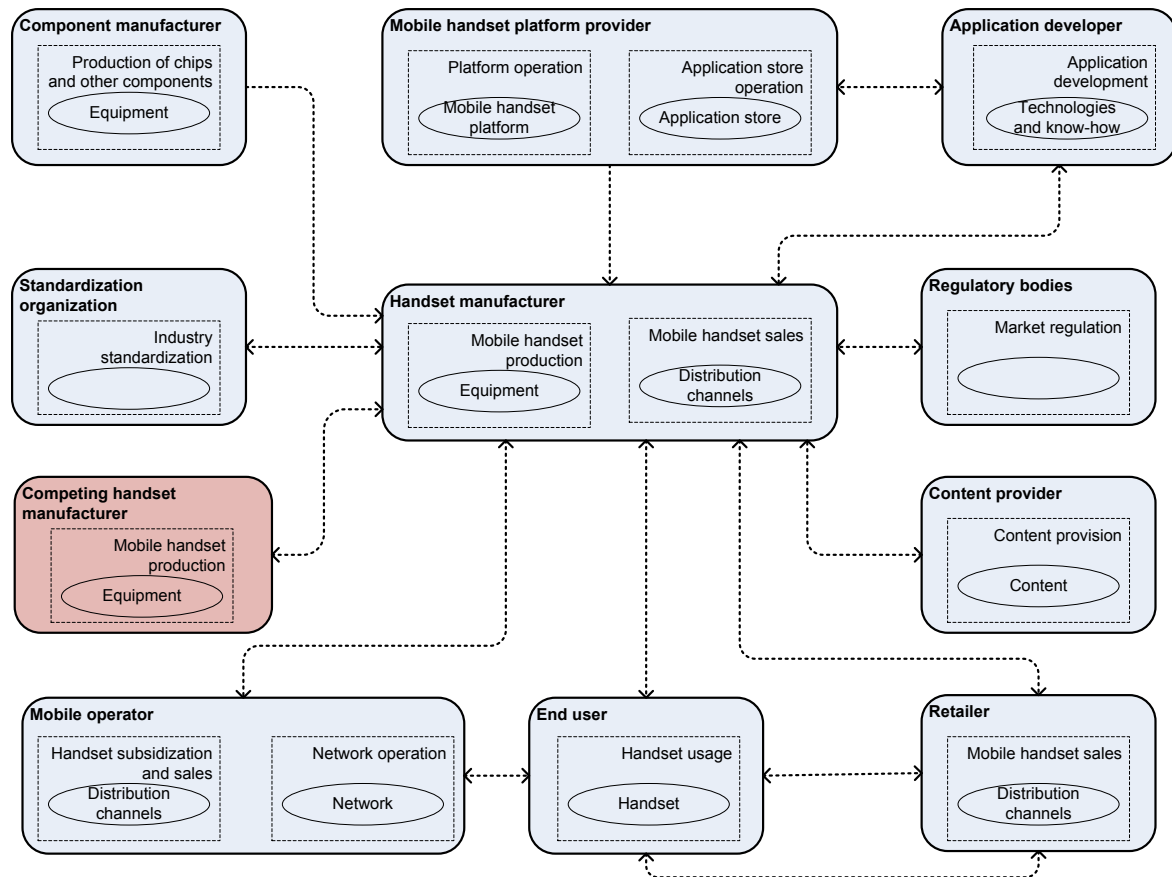


Figure 6.4. Vertically integrated value network of the smartphone industry



**Figure 6.5. Horizontal value network of smartphone industry**

Although the most of the roles presented in the value networks are self-evident, some of them require explanation:

- The role of *platform operation* implies the development and management of a mobile device platform, or a mobile operating system, which acts as the basis for the functioning of smartphones, tablets, and some other mobile devices. The largest mobile platforms are Android, iOS, and Windows Phone, which are managed by Google, Apple, and Windows respectively.
- The role of *application store operation* involves the management of an app store, which can be defined as a distribution platform for mobile applications. The largest mobile platforms have their own app marketplaces: App Store, Google Play, and Windows Phone Store serve respectively iOS, Android, and Windows Phone running devices. However, it should be noted that apart from Google Play, Android applications are available in more than 30 different app stores, including global and regional marketplaces, managed by numerous content aggregators and handset manufacturers (One Platform Foundation, 2014).

Apart from the illustration of the stakeholders and their roles, the value networks allow to analyse the influences between the actors. Considering that some of these connections have a direct effect on developing new mobile handsets, the experts were asked to select several strongest influences affecting mobile handset design decisions (Table 6.1). As the table

suggests, the smartphone revolution, which happened after the launch of the first iOS and Android devices, was marked by a power shift in the industry. According to some of the interviewees, mobile operators lost some of their market power, whereas end users, chipset manufacturers, and application developers became more influential.

**Table 6.1. The most influential stakeholders of the smartphone industry**

<b>Stakeholder</b>	<b>Commentary</b>
<b>Mobile handset platform provider</b>	Platform provider sets minimal requirement for the feature inclusion in the handsets operating based on the platform ( <b>HM3, HMT</b> ). For example, Windows Phone-running handsets must include WLAN, GPS, and 3G ( <b>HM3</b> ). Moreover, before the launch of a new feature, its support must be implemented on the level of OS ( <b>EDU, HM2, HM3</b> ).
<b>Component manufacturer</b>	Due to the market consolidation, electronic component (chipset) producers gain increasing power over handset manufacturers. They define which chipsets to produce, whereas handset manufacturers mainly purchase available solutions without active participation in the development activities ( <b>HM2, HMT</b> ). Five to ten years ago the market of mobile circuits was less consolidated, and mobile manufacturers had more power over the chipset producers ( <b>HMT</b> ).
<b>Mobile operator</b>	The power of mobile operators over handset manufacturers has significantly decreased within last five to ten years ( <b>EDU, HMT, SC</b> ). However, the requirements of mobile operators are still considered to some extent when designing new mobile handset models. This is true at least for the manufacturers with low market power ( <b>HMT</b> ).
<b>End user</b>	The power of end users has increased in last five to ten years as a result of increasing competition ( <b>HM1, HMT</b> ). Moreover, the end users can be considered as influential stakeholders because of the word of mouth: the feedback of the users has great impact on the decision of prospective buyers to purchase the product ( <b>HM1</b> ).
<b>Application developer</b>	Application experience is a driving force of mobile market evolution ( <b>HM4</b> ); therefore, application developers have significant power over the handset manufacturers. Handsets are designed in a way that app experience is optimized. Presently the evolution of mobile industry is software-driven, thus, the ability to run applications is a decisive factor in buying a handset ( <b>HMT</b> ).



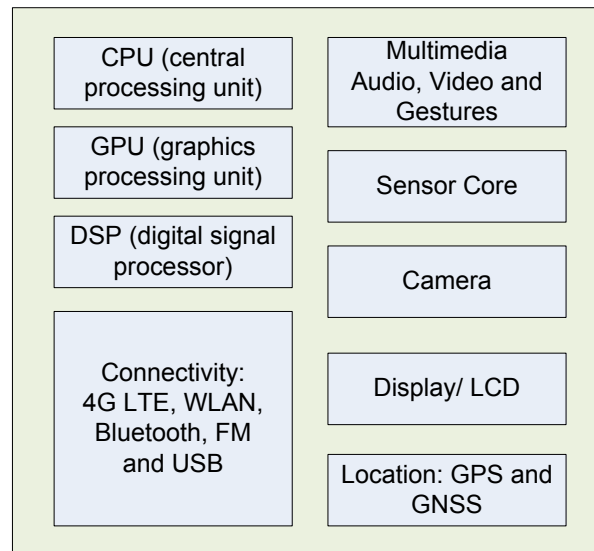
### 6.3 Roles of components and applications in mobile handset feature dissemination

Considering the importance of component manufacturers and application providers in design of mobile handsets and feature dissemination, this section attempts to uncover the ways in which the evolution of component and application populations can be related to the evolution of feature population.

#### 6.3.1 Hardware components

Technology roadmap can be defined as a plan of technology evolution for meeting certain product and performance targets (Garcia & Bray, 1997). Emergence and diffusion of hardware mobile handset features inherently depend on the development of the corresponding components. In order to investigate this relationship in more detail, the experts were asked the following question: “What is the connection between chipset evolution and feature dissemination?”

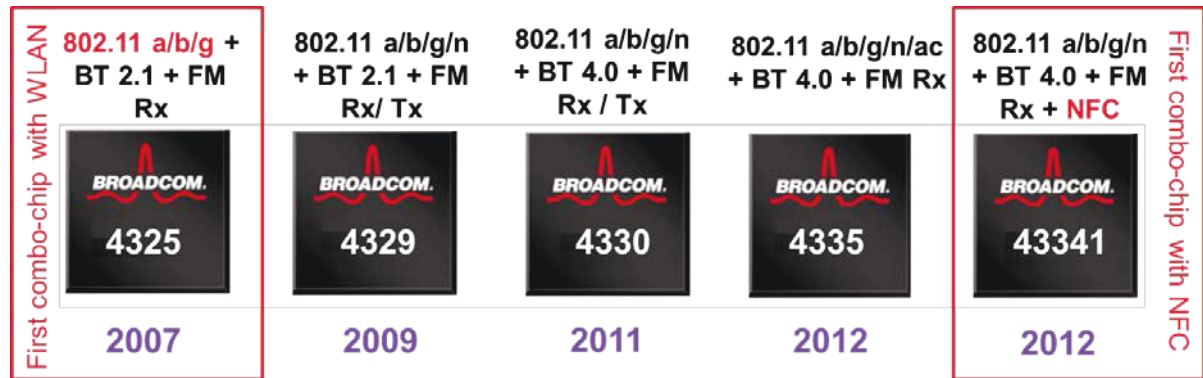
One of the ongoing trends of the evolution of mobile circuits, acknowledged by all seven experts, is chipset integration, entailing the implementation of several previously separated chips on a single die. The reasons for the attractiveness of integrated chipset solutions are reduced component size and price, as well as improved feature performance and energy efficiency (**HM3**, **HMT**). Hence, the majority of the smartphones are built based on an integrated microchip, called system on a chip (SoC).



**Figure 6.6. The structure of Snapdragon 600 SoC (based on Qualcomm, 2014)**

Figure 6.6 provides an example of a structure of Snapdragon 600, SoC produced by Qualcomm, one of the leading semiconductor companies. This SoC is utilised in HTC One, Samsung Galaxy S4, LG Optimus G Pro and some other smartphone models (Qualcomm, 2014). Snapdragon 600, like most of the Snapdragon chips, includes, inter alia, WLAN, Bluetooth, and FM radio connectivity. It should be highlighted that actually Snapdragon SoC integrate baseband radio processors, whereas for the operation of the connectivity

features handset must also include radio frequency (RF) transceivers (Klug, 2013), which are typically supplied separately. Broadcom connectivity chips are often used for complementing the SoC in contemporary smartphones. The evolution of connectivity chips also follows the trend of integration, as can be seen in Figure 6.7.



**Figure 6.7. Evolution of Broadcom connectivity chips<sup>4</sup>**

The experts noted that the chipset integration has a direct effect on the feature dissemination. All seven interviewees agreed that the integration of WLAN to the chipset with Bluetooth and FM radio became one of the reasons of the feature's fast penetration among the smartphones. Moreover, the experts concluded that the recent inclusion of the NFC into Broadcom 43341 combo-chip will most probably facilitate the feature's faster adoption. SC noted that the chipset prices decrease quite rapidly after the launch due to the economy of scale and competition. Therefore, in order to maintain profits, chipset providers are forced to innovate and offer evolved versions of chips to the manufactures, so that the cost of mobile circuits stays relatively at the same level. Thus, according to SC, the price of Broadcom's BCM4325 in 2007 was approximately the same as the price of BCM43341 in 2012.

Furthermore, technology roadmaps of chipset producers can be utilised as a predictor of feature dissemination, since the chipsets are planned and developed in at least 2-3 years prior to the their appearance in mobile devices (HMT). However, if the chipset provider plans to produce a certain chipset, it does not guarantee that it will be eventually launched, because the production plans are adjusted based on the interest and orders of the mobile device manufacturers. Moreover, four out of seven experts mentioned that the existence of feature component does not imply feature's successful diffusion. Thus, mobile TV and Wi-Max failed to diffuse even though the chipsets were available.

Moreover, the presence of a feature component in the handset does not mean that the feature will be enabled and available to the users. Thus, according to the teardowns of Samsung Galaxy S4 (Ifixit, 2014a), HTC One (Ifixit, 2014b), and Apple iPhone 5S (Ifixit, 2014c), all three handset models are equipped with the Broadcom chipsets, capable of FM radio reception (BCM4335 in case of the former two and BCM4334 in case of the latter one). However, out of the mentioned three smartphones, only HTC One has FM radio

<sup>4</sup> Based on the information from <http://www.broadcom.com>

enabled. As five out of seven experts agreed, the absence of FM radio is caused not by the intention to reduce the bill of materials, but rather can be explained by the manufacturers' decisions to abandon FM radio in favour of the Internet radio or own digital media store (Apple's iTunes Store) (**HM3**, **HM4**).

Overall, the development of mobile handset components is inextricably linked with the evolution of mobile handsets, and therefore with the emergence and dissemination of mobile handset features. Taking into account a time lag between the start of feature component development and the start of feature dissemination, the feature emergence can be tracked by the chipset roadmaps. However, it is only possible if previously confidential roadmaps become publicly available information. Moreover, the roadmaps should be interpreted with caution: now always planned chipset is eventually produced and sometimes the feature fails to disseminate even if the chipset is available.

### **6.3.2 Software applications**

Since many mobile applications are enabled by particular handset features, it is intuitively correct to assume the existence of the casual relationship between demand for feature-enabled mobile applications and dissemination of the feature. The validity of this assumption was checked by asking experts' opinion.

**EDU** claimed that the wider availability of a feature can lead to the increasing number of offered application and services enabled by the feature. **HM3** and **HM4**, in turn, agreed that when the feature is just introduced, the emergence of the feature-based applications seems to be caused by the feature dissemination. However, once there are many feature-enabled applications, the causality direction changes: mobile manufacturers become more interested in including the feature in other handset models so that the end users of their products can run the feature-enabled applications.

Commenting the application-related factors of mobile handset design, **SC** considered the example of Apple's M7 motion co-processor. Apple M7 is a sensor which was first introduced in September 2013 in order to improve iPhone's energy efficiency by allowing fitness applications to track physical activity without constantly engaging the main A7 processor (Apple, 2013). This example illustrates the way in which application requirements can cause the development of a new hardware component.

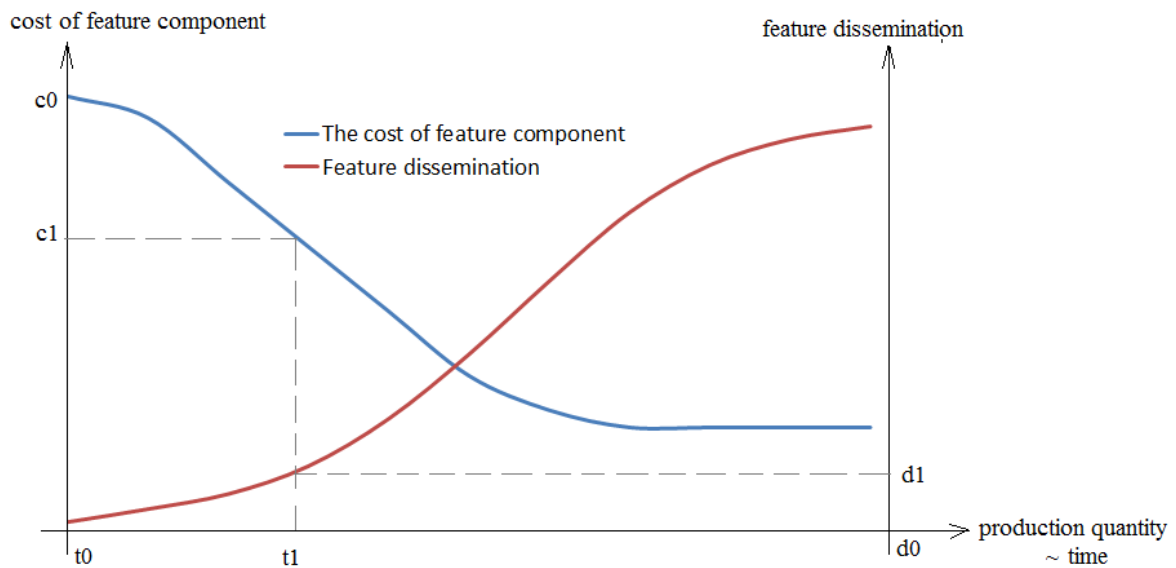
Overall, mobile applications play particularly important role in the industry ecosystem. **HMT** noted that the evolution of mobile handset industry can be described by three waves: hardware, software, and content. During the hardware wave, the ecosystem was built around the handset manufacturers and the quality of hardware was the main decisive factor when choosing a new handset. The ongoing stage of the evolution can be referred to as a software wave and characterized by customers' high prioritization of the mobile application experience, and low attention to the hardware. The emerging wave of content is defined by focusing on the access to the content, regardless of hardware and software channels. In this context, Amazon may become strong and highly competitive industry player.

## 6.4 Directions of the improvement of the mobile handset feature dissemination forecasting

This section presents three main directions of the improvement of the mobile handset feature dissemination forecasting, developed primarily based on the outcomes of expert interviews.

### 6.4.1 Economies of scale

As was acknowledged by all seven experts, the cost of a feature component is one of the main determinants of the feature inclusion in a mobile handset model. Due to the economies of scale, the cost of a component reduces with the increased production; and production, in turn, grows over time. When the component cost has decreased to a particular level, manufacturers start to include it in lower-end handsets, which results in increasing feature dissemination. Therefore, it is logical to assume the existence of the connection between the cost of the feature component and dissemination of the feature, as illustrated qualitatively in Figure 6.8. Analysis of this connection can be fruitful for forecasting the dissemination of emerging features.



**Figure 6.8. Connection between the component cost and feature dissemination**

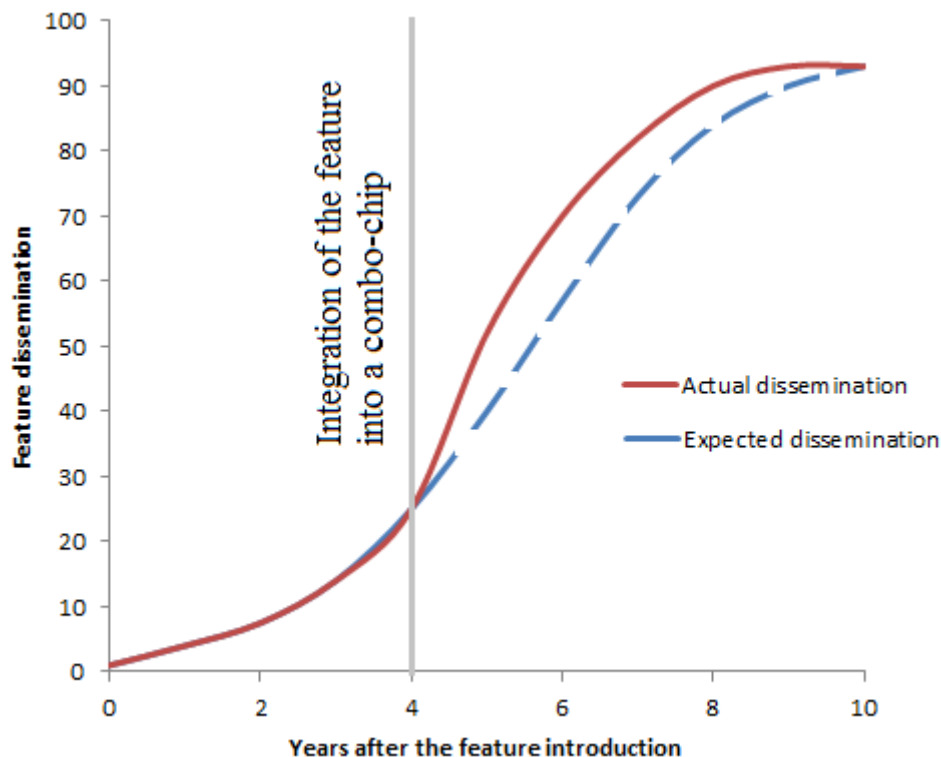
For the analysis, it is necessary to have the information on the average costs of mature feature components and dissemination of these features at different time points. While the latter information can be available from market research companies, such as GfK, the former one is more difficult to obtain. In order to overcome this lack of information, the average retail price of mobile handsets equipped with the feature can be possibly used instead. After plotting the relationships of the average price of handsets equipped with a feature and the feature's dissemination over time for all mature features, the cases should be compared with each other. If the similarities between different features can be observed

and explained, the identified connections between retail price and dissemination can be used for forecasting the dissemination of emerging mobile handset features.

Overall, whereas theoretically it seems probable to observe the connection between the component cost and feature dissemination, in reality it might be problematic because of several reasons. First, the lack of accurate information: apart from the cost of feature component, handset retail price includes many other expenses, which makes it difficult to consider the cost of the focus feature separately from the other costs. Ideally, comprehensive analysis requires the information on included chipsets for all historical handset models, as well as the prices of these chipsets and handsets. Second, the evolution of mobile chipsets does not stand still: while the cost of older chip is decreasing, chipset providers can introduce evolved version of it, which provides enhanced experience, or integrate the feature with some others. In this case, either the prices of both older and newer chips should be considered, or only the price of the cheapest one should be taken into account.

#### 6.4.2 Chipset integration

All seven interviewed experts agreed that integration of a new feature into a combo-chip with older features facilitates faster dissemination of the former one. Qualitatively this phenomenon can be illustrated as shown in Figure 6.9.



**Figure 6.9. Adjustment of feature dissemination after the feature integration into a combo-chip**

It should be noted that based on the analysis of handset sales in Finland, the author did not find evidence of the acceleration of WLAN dissemination after the launch of the first WLAN combo-chip in 2007. However, this and other cases of chipset integration should be studied in more detail in order to prove or disprove the existence of the effect of chipset integration on the rate of feature dissemination and evaluate the strength of the effect if it exists. Moreover, the analysis should consider the price difference between the integrated and standalone chips, as well as demand for the feature and other factors.

#### **6.4.3 Demand for mobile apps**

Some of the experts noted the existence of the casual relationship between feature dissemination and demand for mobile applications enabled by the feature. Hence, this connection should be investigated and used for improving the feature dissemination forecasts.

For the analysis, it is necessary to have the information about the most popular mobile applications enabled by features, as well as the demand for these applications and dissemination of the features. Whereas the dissemination information is accessible, the analysis may be challenged by the lack of the centralized data on mobile applications and corresponding features-enablers. Moreover, the definition of demand for the group of feature-enabled mobile apps is ambiguous: it can be measured as the number of available applications related to the group, or the number of downloads of these apps from the stores. Furthermore, not every feature can be related to the group of mobile applications. For example, LTE can be used for HD video streaming and Internet surfing in general, and these use cases do not require separate mobile applications apart from a web browser.

Overall, even though there is an intuitive connection between dissemination of a feature and demand for the mobile applications enabled by the feature, its consideration for the purpose of dissemination forecasting is challenging due to the lack of data.

## **7 Conclusions**

### **7.1 Key findings**

The era of smartphones began in 2007-2008, with the introduction of the first iOS and Android-running handsets. However, only in 2013 did the number of smartphones in Finland finally surpass the number of feature phones. As a consequence of rapid smartphone commoditization, previously advanced mobile handset features, such as GPS, WLAN, and HSDPA, have now penetrated more than 50% of the handsets in Finland. Therefore, hardware components become less important for handset differentiation than they were previously. At the same time, operating system and other software features turn into decisive factors in customer's handset selection. Indeed, most of the smartphones of the same price category include similar hardware, and customers decide which smartphone to purchase mainly based on the operating system.

Logically, handsets of different price categories differ in the included sets of components. This results in interdependent hierarchical patterns of mobile handset feature dissemination. Thus, whereas low-end handsets typically contain a basic entry-level feature bundle, the high-end handsets, apart from the entry-level features, also include more advanced components. Hence, the features supplied in one bundle are interdependent, whereas less advanced features are asymmetrically dependent on the higher level ones. Example of an interdependent feature bundle in handset sales in 2013 is GPRS, EDGE, Bluetooth, and camera, while an asymmetric connection of the features can be illustrated by the dependency of multitouch, WLAN, GPS and some other features on LTE or NFC. The feature bundling and consequent dissemination patterns arise from the decisions of mobile handset manufacturers, which are responsible for the selection of the features to be included in different mobile handset models. These decisions are influenced by a number of aspects, which were inspected using expert interviews.

The interviews showed that mobile handset design decisions are affected by demand, technology, product strategy, as well as standardisation and regulatory factors. Each group of factors can be related to the industry stakeholders. Some of them can influence the design of new mobile handsets to a greater extent than the others. Presently, component manufacturers, mobile platform providers, end users, and application developers seem to have the most significant impact on the development of new handset models. However, before 2007-2008, the distribution of power in the industry was different: mobile operators could greatly dictate the design of handset models, whereas the component manufacturers and end users, in contrast, influenced the mobile handset producers to a smaller extent.

The identified influencing factors and stakeholders allow for better understanding of the phenomenon of mobile handset feature dissemination. Therefore, the findings can be utilised in order to improve the accuracy of forecasting the feature dissemination, and, consequently, feature diffusion in the following ways. First, the connection between the component cost and the feature dissemination should be studied and taken into account. Second, the effect of chipset integration on the dissemination of the features should be

evaluated and considered for producing future dissemination forecasts. Finally, the demand for mobile apps enabled by a feature can be thought of as a driver for the feature's faster dissemination and therefore can be utilised for improving the diffusion forecast.

## **7.2 Discussion**

The purpose of this research was to study the processes underlying the phenomenon of mobile handset dissemination and suggest improvements to the forecasting of mobile handset feature diffusion.

The thesis assumes that mobile handset feature dissemination is a supply-related process primarily driven by the handset manufacturers. Although one can support the opposite point of view and claim that the feature dissemination is mainly a demand-driven phenomenon, the author would disagree. If the component is supplied in most mobile handset models, the lack of end users' demand for the corresponding feature can hardly cause the failure of its dissemination. The point is that the features are supplied in bundles; therefore, if the user wants to obtain one feature, he will additionally get all the other features from the bundle, regardless of the user's will. Whereas this bundling can be partially explained by the feature complementarity (e.g., GPS and 3G), some components of the bundles are not complements (e.g., Bluetooth and WCDMA). Bundling, therefore, is one of the main reasons for the gap between the feature possession and usage levels: whereas about 90% of the handsets in Finland are equipped with Bluetooth, the feature has never been used in some of these handsets.

However, the supply-related character of the dissemination process does not imply that demand of the end users has no effect on the feature dissemination. Instead, it is one of the most important aspects which is considered when planning new handset models. Mobile manufacturers do not invest money in the development of a new feature (technology, component) if they are not sure that the customers consider it to be useful. However, apart from the end-users, the design of new mobile handsets can be influenced by some other stakeholders, such as mobile platform providers, mobile application developers, and component manufacturers. Understanding these impacts can be beneficial for producing more accurate estimates of handset feature dissemination and diffusion.

Component manufacturers can have a direct effect on the feature dissemination. Indeed, the feature gets more disseminated as it is included in larger number of handset models of different price categories. The feature appears in cheaper handsets when the component providers decrease its price. Therefore, there seems to be a relationship between the feature component cost and its dissemination. Furthermore, the introduction of the combo-chips integrating several features might facilitate dissemination of the features. This seems to be correct logically, but has not yet been proven practically. Finally, growth of the demand for the feature-enabled mobile applications can be also thought of as a facilitator of faster feature dissemination. This idea, although verified by some experts, is difficult to check practically because of the restricted data availability.



Although the thesis research presented several important findings, it has numerous limitations that should be considered when interpreting the results. First, the analysed mobile handset features are mainly hardware component-based (14 out of 15, with the exception of Smartphone OS). Second, most of the studied features are mature and penetrated at least 50% of the total mobile handset population in Finland (12 out of 15 considered features). Moreover, the present research is bound by binary feature variables only, and does not consider diffusion of the features measured on a continuous scale (e.g., size of display, CPU frequency). These limitations lower the relevance of the results and introduce bias into the findings. In order to overcome these limitations, one should consider other software and hardware features, not be restricted to the binary variables only.

This thesis illustrated the dependencies between mobile handset features in a simple and intuitive way. However, conditional probability is not a formal measure of the degree of association between two events due to several reasons. In particular, conditional probability does not allow us to recognise false dependencies. For example, if two features are present in absolutely all handsets, conditional probabilities between them both ways will be equal to one. However, the presence of the first feature does not increase the probability of the occurrence of the second one. Nevertheless, it should be underlined that this issue was considered while defining feature dependency in this thesis. A more formal metric of the dependency between the events is mutual information that measures the information that two events share, and defines the extent to which the knowledge of one variable decreases uncertainty about the other. However, this metric was not used because its interpretation is less intuitive than in case of conditional probability. Another weakness of the presented dependency study is poor consideration of the dynamics of feature dependencies. The analysis of two time points has showed that the dependencies are not static, but it has not allowed tracking of the evolution of the connections.

Although the interview study is a relatively reliable method to elicit the needed information, it also introduces certain limitations into the research. Particularly in the case of this study, most of the interviewed experts represented mobile handset manufacturing companies; therefore, their vision of the research problems was quite similar. The study could be improved by interviewing the representatives of circuit manufacturing companies, developers of popular mobile applications, and experts from the side of mobile platforms. Another limiting factor in the interview study was the interviewer's lack of knowledge in the field of microelectronics, which resulted in the construction of non-optimal interview questions.

Finally, one of the main limitations of the research is that no quantitative improvements were suggested to feature dissemination forecasting model. Nevertheless, some directions of improvement were indicated, and a related quantitative study can be conducted once necessary data becomes available.

### **7.3 Future research**

This thesis uncovered the processes underlying the phenomenon of feature dissemination and suggested improvements to the feature dissemination forecasting model. However, implementation of the suggestions, as has been noted before, is left for future research. Furthermore, a future study should address the limitations of the current research, presented in the previous section.

Whereas the analysed case of Finland is representative for most developed countries, further research should address the dissemination and diffusion of mobile handset features in developing countries as well. This forecasting of mobile handset feature diffusion in developing countries is relevant because the penetration of smartphones is not that high and therefore, the markets of developing countries are large opportunities for smartphone producers as well as application developers.

This thesis, in line with Kivi et al. (2012), focused on the study of mobile handset features, while a similar algorithm of discovering the phenomenon of feature dissemination can be generally applied to the features of other technological products. Moreover, the feature diffusion forecasting framework should be also tested on the components of different products.

## References

- 3GPP. (2014a). *About 3GPP*. Retrieved June 25, 2014 from <http://www.3gpp.org/about-3gpp/about-3gpp>
- 3GPP. (2014b). *Releases*. Retrieved June 25, 2014 from <http://www.3gpp.org/specifications/67-releases>
- Adner, R., & Kapoor, R. (2010). Value creation in innovation ecosystems: How the structure of technological interdependence affects firm performance in new technology generations. *Strategic management journal*, 31(3), 306-333.
- Adomavicius, G., Bockstedt, J. C., Gupta, A., & Kauffman, R. J. (2007). Technology roles and paths of influence in an ecosystem model of technology evolution. *Information Technology and Management*, 8(2), 185-202.
- Agrawal, R., Imieliński, T., & Swami, A. (1993, June). Mining association rules between sets of items in large databases. In *ACM SIGMOD Record* (Vol. 22, No. 2, pp. 207-216). ACM.
- Apple. (2013). *iPhone 5S specifications* [Fact sheet]. Retrieved June 25, 2014 from <http://www.apple.com/iphone-5s/features/>
- Bass, F. M. (2004). Comments on “a new product growth for model consumer durables the bass model”. *Management science*, 50(12\_supplement), 1833-1840.
- Bass, F. M., Krishnan, T. V., & Jain, D. C. (1994). Why the Bass model fits without decision variables. *Marketing science*, 13(3), 203-223.
- Bass, F.M.. (1969). A New Product Growth Model For Consumer Durables. *Management Science*, 15(5), 215-227.
- Bhushan A. (2013). *Jolla Sailfish Operating System (OS) Now Supports Android Hardware And Applications*. Retrieved June 25, 2014 from <http://ceoworld.biz/2013/09/16/jolla-sailfish-operating-system-os-now-supports-android-hardware-and-applications>
- Bickel, P. J., & Lehmann, E. L. (2012). Frequentist interpretation of probability. In *Selected Works of EL Lehmann* (pp. 1083-1085). Springer US
- Blind, K. (2011). *The Benefits of Standards for National Economies*. Retrieved June 25, 2014 from <http://www.worldstandardscooperation.org/newsletters/003/newsletter03.html>
- Brancheau, J. C., & Wetherbe, J. C. (1990). The adoption of spreadsheet software: testing innovation diffusion theory in the context of end-user computing. *Information Systems Research*, 1(2), 115-143.
- Brem, A., & Voigt, K. I. (2009). Integration of market pull and technology push in the corporate front end and innovation management—Insights from the German software industry. *Technovation*, 29(5), 351-367.

- Business Dictionary. (2014). *Product strategy*. Retrieved June 25, 2014 from <http://www.businessdictionary.com/>
- Casey, T., Smura, T., & Sorri, A. (2010, June). Value Network Configurations in wireless local area access. In *Telecommunications Internet and Media Techno Economics (CTTE), 2010 9th Conference on* (pp. 1-9). IEEE.
- Chidamber, S. R., & Kon, H. B. (1994). A research retrospective of innovation inception and success: the technology-push, demand-pull question. *International Journal of Technology Management*, 9(1), 94-112.
- Chu, W. L., Wu, F. S., Kao, K. S., & Yen, D. C. (2009). Diffusion of mobile telephony: An empirical study in Taiwan. *Telecommunications Policy*, 33(9), 506-520.
- Cisco. (2014). *Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2013-2018* [White paper]. Retrieved June 25, 2014 from [http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white\\_paper\\_c11-520862.pdf](http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white_paper_c11-520862.pdf)
- Coleman, J. S., Katz, E., & Menzel, H. (1966). *Medical innovation: A diffusion study*. Indianapolis: Bobbs-Merrill Company.
- Costa-Pérez, X., Festag, A., Kolbe, H. J., Quittek, J., Schmid, S., Stiernerling, M., ... & van der Veen, H. (2013). Latest trends in telecommunication standards. *ACM SIGCOMM Computer Communication Review*, 43(1), 64-71.
- Deidu, H.H. (2010). *Absolute value: the handset market stacked*. Retrieved June 25, 2014 from <http://www.asymco.com/2010/11/02/absolute-value-the-handset-market-stacked/>
- Denning, P. J. (2004). The social life of innovation. *Communications of the ACM*, 47(4), 15-19.
- DiCicco-Bloom, B., & Crabtree, B. F. (2006). The qualitative research interview. *Medical education*, 40(4), 314-321.
- FCC. (2014). *Hearing Aid Compatibility for Wireless Telephones*. Retrieved June 25, 2014 from <http://www.fcc.gov/guides/hearing-aid-compatibility-wireless-telephones>
- Fliegel, F. C., & Kivlin, J. E. (1966). Attributes of innovations as factors in diffusion. *American Journal of Sociology*, 235-248.
- Frankfort-Nachmias, C., & Leon-Guerrero, A. (2010). *Social statistics for a diverse society*. Pine Forge Press.
- Garcia, M. L., & Bray, O. H. (1997). *Fundamentals of technology roadmapping*. Albuquerque, NM: Sandia National Laboratories.
- Gerpott, T. J. (2005). Strategisches technologie-und innovationsmanagement
- Gompertz, B. (1825). On the nature of the function expressive of the law of human mortality, and on a new mode of determining the value of life contingencies. *Philosophical transactions of the Royal Society of London*, 513-583.

- GSM Arena. (2014). *Multitouch input method*. Retrieved June 25, 2014 from <http://www.gsmaarena.com/glossary.php3?term=multitouch>
- GSMA Intelligence. (2014). *From concept to delivery: the M2M market today. Analysis*. Retrieved June 25, 2014 from <https://gsmaintelligence.com/files/analysis/?file=140217-m2m.pdf>
- Hipp, J., Güntzer, U., & Nakhaeizadeh, G. (2000). Algorithms for association rule mining—a general survey and comparison. *ACM SIGKDD Explorations Newsletter*, 2(1), 58-64.
- Ifixit. (2014a). *Samsung Galaxy S4 Teardown*. Retrieved June 25, 2014 from <https://www.ifixit.com/Teardown/Samsung+Galaxy+S4+Teardown/13947>
- Ifixit. (2014b). *HTC One Teardown*. Retrieved June 25, 2014 from <https://www.ifixit.com/Teardown/HTC+One+Teardown/13494>
- Ifixit. (2014c). *iPhone 5s Teardown*. Retrieved June 25, 2014 from <https://www.ifixit.com/Teardown/iPhone+5s+Teardown/17383>
- Islam, T., & Meade, N. (2000). Modelling diffusion and replacement. *European Journal of Operational Research*, 125(3), 551-570.
- Kamakura, W. A., & Balasubramanian, S. K. (1987). Long-term forecasting with innovation diffusion models: The impact of replacement purchases. *Journal of Forecasting*, 6(1), 1-19.
- Kijek, T., & Kijek, A. (2010). Modelling of innovation diffusion. *Operations Research and Decisions*, 20(3-4), 53-68.
- Kivi, A., Smura, T., & Töyli, J. (2012). Technology product evolution and the diffusion of new product features. *Technological Forecasting and Social Change*, 79(1), 107-126.
- Klug, B. (2013). *The state of Qualcomm's Modems – WTR1605 and MDM9x25*. Retrieved June 25, 2014 from <http://www.anandtech.com/show/6541/the-state-of-qualcomms-modems-wtr1605-and-mdm9x25>
- Mahajan, V., & Peterson, R. A. (Eds.). (1985). *Models for innovation diffusion* (Vol. 48). Sage.
- Mahajan, V., Muller, E., & Bass, F. M. (1990). New product diffusion models in marketing: A review and directions for research. *The Journal of Marketing*, 1-26.
- Mahajan, V., Muller, E., & Bass, F. M. (1995). Diffusion of new products: Empirical generalizations and managerial uses. *Marketing Science*, 14(3\_supplement), G79-G88.
- Martinez, E., Polo, Y., & Flavian, C. (1998). The acceptance and diffusion of new consumer durables: differences between first and last adopters. *Journal of Consumer Marketing*, 15(4), 323-342.
- McNamara, C. (2014). *General guidelines for conducting interviews*. Retrieved June 25, 2014 from <http://managementhelp.org/businessresearch/interviews.htm>

- Meade, N. (1984). The use of growth curves in forecasting market development—a review and appraisal. *Journal of Forecasting*, 3(4), 429-451.
- Meade, N., & Islam, T. (1998). Technological forecasting—Model selection, model stability, and combining models. *Management Science*, 44(8), 1115-1130.
- Moore, J. F. (1996). *The death of competition: leadership and strategy in the age of business ecosystems*. New York: HarperBusiness.
- Motorola. (2014). *Interactive timeline of Motorola innovations* [Fact sheet]. Retrieved June 25, 2014 from [http://www.motorola.com/us/consumers/about-motorola-us/About\\_Motorola-History-Timeline/About\\_Motorola-History-Timeline.html](http://www.motorola.com/us/consumers/about-motorola-us/About_Motorola-History-Timeline/About_Motorola-History-Timeline.html)
- Norton, J. A., & Bass, F. M. (1987). A diffusion theory model of adoption and substitution for successive generations of high-technology products. *Management science*, 33(9), 1069-1086.
- Olson, J., & Choi, S. (1985). A product diffusion model incorporating repeat purchases. *Technological Forecasting and Social Change*, 27(4), 385-397.
- One Platform Foundation. (2014). *List of Android App Stores* [Fact sheet]. Retrieved June 25, 2014 from <http://www.onepf.org/appstores/>
- Organisation for Economic Co-operation and Development. (1997). *The Measurement of Scientific and Technological Activities: Proposed Guidelines for Collecting and Interpreting Technological Innovation Data: Oslo Manual*. OECD.
- Osborne, D. (2005). *Nokia admits N-Gage is a failure*. Retrieved June 25, 2014 from <http://www.geek.com/games/nokia-admits-n-gage-is-a-failure-560162/>
- Oxford Dictionaries. (2014). *Tablet*. Retrieved June 25, 2014 from <http://www.oxforddictionaries.com/>
- Peltoniemi, M. (2005). Business ecosystem: A conceptual model of an organisation population from the perspectives of complexity and evolution. *e-Business Research Center. Research Report 18*.
- Peres, R., Muller, E., & Mahajan, V. (2010). Innovation diffusion and new product growth models: A critical review and research directions. *International Journal of Research in Marketing*, 27(2), 91-106.
- Porter, M. E., & Van der Linde, C. (1995). Green and competitive: ending the stalemate. *Harvard business review*, 73(5), 120-134.
- Qualcomm. (2014). *Snapdragon 600 processors* [Fact sheet]. Retrieved June 25, 2014 from <http://www.qualcomm.com/snapdragon/processors/600>
- Riikonen, A., Smura, T. (2013). Mobile handset population in Finland 2005-2012. MoMIE project report. Aalto University.

- Riikonen, A., Smura, T., & Juntunen, A. (2011). Mobile handset features as service enablers-Conceptual model of feature diffusion. In *Intelligence in Next Generation Networks (ICIN), 2011 15th International Conference on* (pp. 325-330). IEEE.
- Robinson, B., & Lakhani, C. (1975). Dynamic price models for new-product planning. *Management Science*, 21(10), 1113-1122.
- Rogers, E. M. (2003). *Diffusion of innovations* (5th edition). New York, NY: Free Press.
- Strategic Management Insight. (2014). *Vertical Integration*. Retrieved June 25, 2014 from <http://www.strategicmanagementinsight.com/topics/vertical-integration.html>
- Suh, S. (2012). *Practical applications of data mining*. Jones & Bartlett Publishers.
- Tallberg, M., Hämmäinen, H., Töyli, J., Kamppari, S., & Kivi, A. (2007). Impacts of handset bundling on mobile data usage: The case of Finland. *Telecommunications Policy*, 31(10), 648-659.
- Tan, M., & Teo, T. S. (2000). Factors influencing the adoption of Internet banking. *Journal of the AIS*, 1(1es), 5.
- Telecom Paper. (2013). *SK Telecom launches first LTE-A services*. Retrieved June 25, 2014 from <http://www.telecompaper.com/news/sk-telecom-launches-first-lte-a-services--951793>
- Thölke, J. M., Hultinka, E. J., & Robbenb, H. S. (2001). Launching new product features: a multiple case examination. *Journal of Product Innovation Management*, 18(1), 3-14.
- Tornatzky, L. G., & Klein, K. J. (1982). Innovation characteristics and innovation adoption-implementation: A meta-analysis of findings. *Engineering Management, IEEE Transactions on*, (1), 28-45.
- Van Slyke, C., Belanger, F., & Comunale, C. L. (2004). Factors influencing the adoption of web-based shopping: the impact of trust. *ACM Sigmis Database*, 35(2), 32-49.
- Verhulst, P. F. (1838). Notice sur la loi que la population suit dans son accroissement. *Correspondance Mathématique et Physique Publiée par A. Quetelet*, 10, 113-121.
- Walsh, S. T., Kirchhoff, B. A., & Newbert, S. (2002). Differentiating market strategies for disruptive technologies. *Engineering Management, IEEE Transactions on*, 49(4), 341-351.
- Wu, T. (2007). Wireless Carterfone. *International Journal of Communication*, 1, 389-426.

## Appendix A. Interview topics

	Discussed topic	Example of questions asked
1	Interviewee's background information	What is your work experience?
2	Research details: datasets, methods, and objectives	
3	Feature interdependency	What is a high level reason of the feature interdependency in dissemination?
4	Factors affecting mobile handset design decisions	In which ways the defined factors affect mobile handset design decisions and feature dissemination?  Which improvements would you suggest for the predefined conceptual model of the affecting factors?
5	Industry stakeholders	In which ways the defined industry stakeholders affect mobile handset design decisions and feature dissemination?  What are the most influential stakeholders of the industry?  Which improvements would you suggest to predefined value network configurations?
6	Impact of hardware-related factors on feature dissemination	What is the connection between chipset evolution and feature dissemination, if any?  What information about future feature dissemination can be elicited from technology roadmaps?
7	Impact of application-related factors on feature dissemination	What is the connection between demand for mobile applications and feature dissemination, if any?
8	Declining diffusion of FM radio	What are the reasons of the declining diffusion of FM radio?  Can diffusion of other mature features start to decrease?
9	Future feature dissemination	How will the features disseminate further?  How can the forecasting of feature dissemination be improved?